

#### CHROMATE CONTENT BIAS VERSUS OVERSPRAY PARTICLE SIZE IN THREE AIRCRAFT PRIMER PAINTS

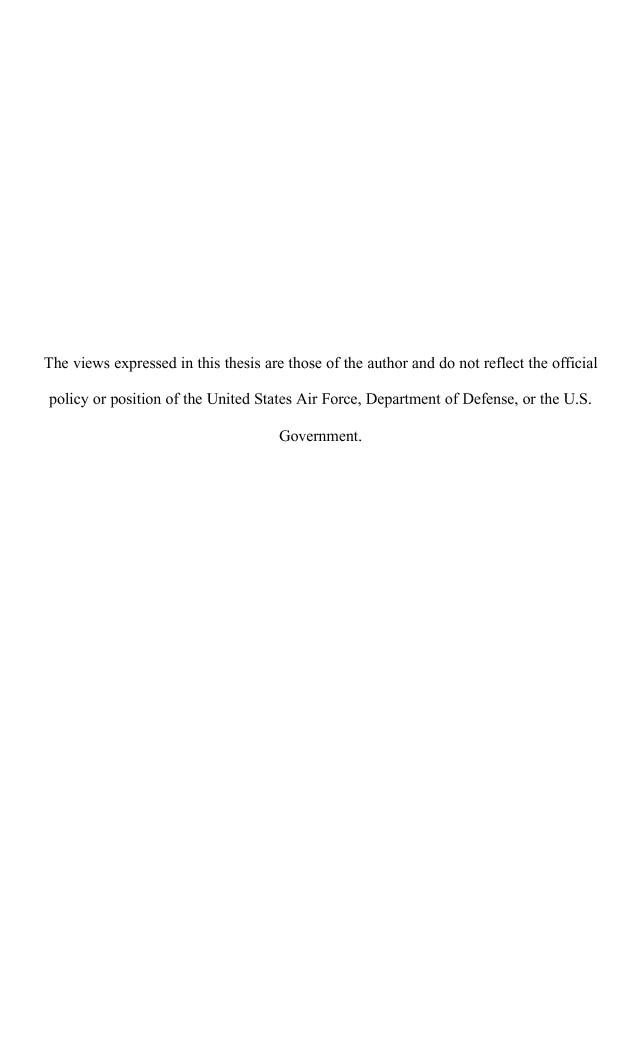
**THESIS** 

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#### THESIS

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#### **Table of Contents**

	rage
Acknowledgements	iv
List of Figures	viii
List of Tables	X
Abstract	xi
I. Introduction	1
Air Force Primer Paint Overview	
II. Literature Review	4
Chromium Health Effects of Chromate Exposure Particle Deposition in the Lung USAF Primer Paint Solvent-Based Epoxy-Polyamide. Water-Based Epoxy-Polyamide. Solvent-Based Elastomeric Polyurethane. Regulatory Exposure Limits Particle Kinetics Atomization Overview. Paint Atomization Device. Liquid Properties. Air-to-Paint Ratio. Secondary Atomization. Particle Collection Paint Overspray Distribution. Previous Overspray Exposure Research Cr <sup>6+</sup> Content Bias.	
III. Methodology	26
Overview Painting Operation Recorded Data Air-to-Paint Ratios. Background Runs.	26 26 27
Overspray Collection Particle Size Ranges Sampling System Sample Preparation Sample Substrates	32 35 36

	Page
Analytical Mass Determination.	36
Sample Dilution	
Sample Dilution	
Calculation of Chromium Content in Dry Paint	
IV. Results	41
Cr <sup>6+</sup> Content per Mass of Dry Paint	
A/P Ratio Influence on Cr <sup>6+</sup> Content	44
Comparison of Cr <sup>6+</sup> Content Bias to Previous Study	
V. Discussion	47
Cr <sup>6+</sup> Content Bias in Different Primers	47
Influence of A/P Ratio on Cr <sup>6+</sup> Content	
Implications of Cr <sup>6+</sup> Content Bias	48
Possible Sources of Cr <sup>6+</sup> Bias	53
APPENDIX A-1: Calculation for Cr <sup>6+</sup> Content in Solvent EP	54
APPENDIX A-2: Calculations for Cr <sup>6+</sup> Content in Water EP	56
APPENDIX A-3: Calculations for Cr <sup>6+</sup> Content in Polyurethane	
APPENDIX B: Deft® Product Data Sheets and MSDS for	
Solvent-Based Epoxy-Polyamide Primer Paint	58
APPENDIX C: Deft® Product Data Sheets and MSDS for	
Water-Based Epoxy-Polyamide Primer Paint	62
APPENDIX D: Deft® Product Data Sheets and MSDS for	
Solvent-Based Elastomeric, Polyurethane Primer Paint	66
APPENDIX E-1: Raw Data Table for	
Solvent-Based Epoxy-Polyamide Primer Paint	70
APPENDIX E-2: Raw Data Table for	
Water-Based Epoxy-Polyamide Primer Paint	71
APPENDIX E-3: Raw Data Table for	
Solvent-Based Elastomeric, Polyurethane Primer Paint	72

	Page
Bibliography	73
Vita	76

#### **List of Figures**

rage
Figure 1. Fractional Deposition of Particles
Figure 2. Illustration of Typical Air Cap (Kwok, 1991)13
Figure 3. Schematic Design of a Cascade Impactor (Hinds, 1982:120)
Figure 4. Actual and Ideal Impactor Cutoff Curves (Hinds, 1982:117) 20
Figure 5. Comparison of Mass Cr per Mass Dry Paint by Manufacturer
(Novy, 2001)25
Figure 6. HVLP Spray Paint Gun with Sample Collection Set-up30
Figure 7. Impactor Layout (Not to Scale)
Figure 8. Particle Size Range by Stage
Figure 9. Sampling System Layout at CTIO Paint Booth
Figure 10. Sample Collection Vacuum Pumps with Rotometers35
Figure 11a. Mass of Cr <sup>6+</sup> per Mass of Dry Paint: Solvent-Based Epoxy-Polyamide
Figure 11b. Mass of Cr <sup>6+</sup> per Mass of Dry Paint: Water-Based Epoxy-Polyamide 43
Figure 11c. Mass of Cr <sup>6+</sup> per Mass of Dry Paint: Solvent-Based Elastomeric
Polyurethane43
Figure 12a. Comparison of Mean Percent Cr <sup>6+</sup> for Different A/P Ratios:
Solvent-Based Epoxy-Polyamide44
Figure 12b. Comparison of Mean Percent Cr <sup>6+</sup> for Different A/P Ratios:
Water-Based Epoxy-Polyamide45
Figure 12c. Comparison of Mean Percent Cr <sup>6+</sup> for Different A/P Ratios:

Page
Solvent-Based Elastomeric Polyurethane45
Figure 13. Comparison of Mass of Cr <sup>6+</sup> per Mass of Dry Paint by Study 46
Figure 14a. $Cr^{6+}$ Deposition in Lung: Solvent-Based Epoxy-Polyamide
(Small Particle-Size Impactor)
Figure 14b. Cr <sup>6+</sup> Deposition in Lung: Solvent-Based Epoxy-Polyamide
(Large Particle-Size Impactor)50
Figure 15a. $Cr^{6+}$ Deposition in Lung: Water-Based Epoxy-Polyamide
(Small Particle-Size Impactor)51
Figure 15b. Cr <sup>6+</sup> Deposition in Lung: Water-Based Epoxy-Polyamide
(Large Particle-Size Impactor) 51
Figure 16a. $Cr^{6+}$ Deposition in Lung: Solvent-Based Elastomeric-Polyurethane
(Small Particle-Size Impactor)
Figure 16b. Cr <sup>6+</sup> Deposition in Lung: Solvent-Based Elastomeric-Polyurethane
(Large Particle-Size Impactor)

#### **List of Tables**

	Page
Table 1. Summary of Primer Product Codes and Chromium Content	10
Table 2. Primer Preparation Specifications (Deft, 2000)	27
Table 3. Pressure Settings and A/P Ratios	28
Table 4. Small Particle Size Range Impactor (18 L/min)	33
Table 5. Large Particle Size Range Impactor (8 L/min)	33
Table 6. Sample Digestion Program	37
Table 7. AAS Graphite Furnace Parameters	39
Table 8. Average Cr <sup>6+</sup> Content per Mass of Dry Primer Paint	41

#### Abstract

The United States Air Force relies on the corrosion inhibiting properties of chromate-containing primer paints to protect the aluminum skin of its aircraft. Hexavalent chromium (Cr<sup>6+</sup>)—the ingredient responsible for the corrosion inhibiting characteristics of these primers—is a known human carcinogen. The concentration of Cr<sup>6+</sup> in different particle sizes of paint overspray is important to understand health implications to painters as well as filtration efficiency. Previous research indicates disproportionately less Cr<sup>6+</sup> content in smaller particles collected in the overspray of solvent-based epoxy-polyamide paint primers (MIL-P-2377G).

This research explores the possibility of a particle size bias in the  $Cr^{6^+}$  content of three commonly used aircraft primers: solvent-based epoxy-polyamide, water-based epoxy-polyamide (MIL-PRF-85582C), and solvent-based polyurethane (TT-P-2760A). The mass ratio of air flow to paint flow (A/P ratio) was varied during initial atomization. Seven-stage cascade impactors collected overspray particles into distinct bins with particle size cutoff diameters ranging from 0.7  $\mu$ m to 34.1  $\mu$ m. The mass of the dry paint collected in each bin was determined and analyzed for  $Cr^{6^+}$  with an Atomic Absorption Spectrometer.

In all three primers, smaller particles contained disproportionately less  $Cr^{6+}$  per mass of dry paint than larger particles. Particles with an aerodynamic diameter under 7  $\mu$ m contained less  $Cr^{6+}$  per mass of dry paint as the particles became smaller. Particles less than 2.6  $\mu$ m have a mean  $Cr^{6+}$  content of approximately one-third of the expected

value. The range of A/P ratios tested in this study had no effect on the  ${\rm Cr}^{6^+}$  content in the overspray.

## CHROMATE CONTENT BIAS VERSUS OVERSPRAY PARTICLE SIZE IN THREE AIRCRAFT PRIMER PAINTS

#### I. Introduction

#### **Air Force Primer Paint Overview**

The United States Air Force (USAF) relies on the corrosion inhibiting properties of paint coating systems to protect its aircraft, which must endure extreme environmental conditions. These coating systems are typically comprised of a surface preparation, a primer coat, and topcoat paint. The primer coat, which is between the surface and the topcoat, provides an adhesive surface for the topcoat. Additionally, the primer contains additives that inhibit oxidation of the aircraft's aluminum skin. These additives are typically chromate (CrO<sub>4</sub><sup>2-</sup>)-containing compounds.

The most commonly used corrosion control additive in primers, strontium chromate (SrCrO<sub>4</sub>), presents the greatest risk of cancer for aircraft painters (California Department of Health Services, 1992). The most commonly used military specifications (MIL-P-23377G, MIL-P-85582B, and MIL-P-87112) and federal specification (TT-P-2760A) that regulate primer paint designate SrCrO<sub>4</sub> or barium chromate as the default corrosion inhibitors (T.O. 1-1-8). Strontium chromate contains chromium in its hexavalent state (Cr<sup>6+</sup>). Cr<sup>6+</sup> is considered a carcinogen by most national and international health and medical agencies (International Agency for Research on Cancer (IARC), 1990).

The primary cancer risk associated with exposure to  $Cr^{6+}$  is through inhalation of  $Cr^{6+}$ -containing dusts, mists, and fumes. Most epidemiology studies that have focused on exposure of workers involved in the production of chromates and  $Cr^{6+}$ -containing

pigments show an excess risk of respiratory cancer. Similar studies that examine the risk of cancer for workers that use Cr<sup>6+</sup>-containing compounds, such as spray painters, are relatively fewer in number and demonstrate a less definitive risk (Dalager *et al.*, 1980:25). It has been suggested that the type of aerosol generated in a process (e.g., liquid aerosols, mists, or dusts) is an important factor in determining the health risk of Cr<sup>6+</sup> (Finley *et al.*, 1992:170).

A number of factors are important when characterizing the harmful effects of  $Cr^{6+}$  inhalation. As with any inhalation hazard, particle size distribution determines the how much material will deposit in various regions of the respiratory system. In general, smaller particles will deposit more deeply in the respiratory system and larger particles will deposit in the upper respiratory region primarily due to impaction, sedimentation, and interception (Schlesinger, 19XX:192). Furthermore, the determination of the percentage of  $Cr^{6+}$  in the particles that are of a size that is readily inhalable is important. Also, investigating any dependence of  $Cr^{6+}$  content on particle size is important since smaller particles tend to deposit more deeply into the respiratory system. The deeper a particle penetrates into the respiratory system, the longer the particle will remain in the system.

In the aircraft painting industry, workers are exposed to  $Cr^{6^+}$  in the paint overspray created from the application of primer on the aircraft surface. The suspension of these  $Cr^{6^+}$ -containing particles presents an inhalation exposure risk to the painters. Therefore, in order to determine the risk to the worker, the distribution of the  $Cr^{6^+}$  over the range of particle sizes in the overspray must be characterized.

#### **Thesis Objective**

This study follows previous work, which found that the larger particles contain disproportionately more Cr<sup>6+</sup> than smaller particles in the overspray of military specification MIL-P-23377G primer, which is a solvent-based epoxy-polyamide primer paint hereinafter referred to as solvent EP primer. (Fox, 2000; Novy, 2001). The focus of this study is to quantify the Cr<sup>6+</sup> distribution as a function of particle size for three commonly used Cr<sup>6+</sup>-containing aircraft primer paints.

The objectives of this study are to:

- Quantify the Cr<sup>6+</sup> content in the oversprays of solvent EP, military specification MIL-PRF-85582C (a water-based epoxy-polyamide primer paint hereinafter referred to as water EP primer), and federal specification TT-P-2760A primer paint (a solvent-based elastomeric, polyurethane primer paint hereinafter referred to as polyurethane primer), and
- Observe whether the air-to-paint (A/P) ratio—a measure describing certain operating conditions of the spray gun—will influence the Cr<sup>6+</sup> distribution in various particle sizes for the solvent EP, water EP, and polyurethane primer paint overspray.

#### II. Literature Review

#### Chromium

Chromium is a naturally occurring element commonly found in the earth's crust. It typically exists in the trivalent  $(Cr^{3+})$ , hexavalent  $(Cr^{6+})$ , or elemental (Cr) states, however, short-term intermediate states can be found including  $Cr^{2+}$ ,  $Cr^{4+}$ , and  $Cr^{5+}$ . Chromium has been recognized as an important metal in a variety of industrial applications as well as an active component in a number of biological processes.

Due to its strong oxidative characteristics,  $Cr^{6^+}$  is used in a wide range of industries, including chemical and metallurgical. Hexavalent chromium—a key component in stainless steel—can be found in the alloy to inhibit oxidation of the iron as well as the protective casing of "chrome-plated" steel compounds. Similarly,  $Cr^{6^+}$  compounds are popular in the painting industry because of their corrosion inhibiting behavior. Additionally,  $Cr^{6^+}$  is universally used as a pigment in paint, ink, and plastic production industries.

Besides its industrial uses, chromium plays an important role in a few key metabolic pathways in the human body.  $Cr^{3+}$  is an essential micronutrient for humans. Although only very small quantities are needed,  $Cr^{3+}$  is necessary for the metabolism of glucose through the potentiation of insulin (Felter, 1997: 43). The National Research Center recommends a minimum Established Safe and Adequate Daily Dietary Intake of 50-200  $\mu$ g (National Center for Complementary and Alternative Medicines, 2000). Although the beneficial aspects of  $Cr^{3+}$  are well documented, more attention is given to the deleterious health effects of  $Cr^{6+}$ , which are discussed in the following section.

#### **Health Effects of Chromate Exposure**

The primary pathways of Cr<sup>6+</sup> exposure are inhalation, ingestion, and dermal contact of chromate-containing compounds. Ingestion is a more prevalent pathway of exposure for children, although workers have been found to ingest Cr<sup>6+</sup> due to poor hygiene at meal and smoking breaks. Dermal contact is generally associated with localized, non-cancerous health effects. The majority of epidemiology studies performed on workplace exposure to Cr<sup>6+</sup> focuses on the excess cancer risks from inhalation, which is also the pathway of greatest concern.

The source of inhalable  $Cr^{6+}$ , predominately found in the form of mists, dusts, and fumes, varies depending on the industrial use of the chromate-containing substance. In spraying operations, fine mists are created during the atomization of the coating liquid. Although respiratory protection and ventilation controls are frequently required in these operations, workers still risk inhalation exposure, as these controls sometimes fail or are overwhelmed. Similarly, in plating operations, chromic acid mist presents an inhalation hazard created by vapor that diffuses to the surface of drip tanks and carries liquid chromic acid particles into the air. Welding is another commonly cited activity that is associated with  $Cr^{6+}$  inhalation. In this case, the  $Cr^{6+}$  exposure results from the intense heat applied to the stainless steel or chromium-coated material, thus changing the solid metal into a  $Cr^{6+}$  fume (CDHS, 1992).

As previously noted,  $Cr^{6+}$  is widely recognized for its carcinogenic potential. IARC sites numerous studies that show evidence for carcinogenicity of chromatecontaining compounds, including strontium chromate, in experimental animals. In a study of the carcinogenicity potential of chromium-containing materials, Levy *et al.* 

found that strontium chromate and, to a lesser extent, zinc chromate caused bronchial carcinomas in rat lungs (Levy *et al.*, 1986: 243). In this study, an intrabronchial implantation system was used to dose the rats with the test material in pellet form.

The IARC and other agencies also conclude that Cr<sup>6+</sup> compounds are carcinogenic to humans based, in part, on several epidemiology studies of workers in the chromate production, chromate pigment production, and chromium plating industries (IARC, 1997) which show an elevated risk of lung cancer.. In an early study, Mancuso (1975) reported an elevated risk of lung cancer in chromate production workers. However, this study did not record the smoking habits of the study group. Therefore, smoking—a leading cause of bronchial carcinomas—could not be discounted as a possible confounding factor. Gibb *et al.* (2000) repeated this effort in a cohort study of 2357 workers in the chromate production industry. With improved background history of the study subjects, Gibb *et al.* were able to determine that the excess risk of lung cancer was not confounded by the prevalence of smoking among workers.

As compared to the findings in the aforementioned industries, the relatively few studies that focused on the carcinogenicity of chromium in the painting industry have reported conflicting data. In a study of 4760 deceased spray painters from ten automobile assembly plants that used paints with chromate pigments, no statistically significant proportionate mortality ratio (PMR) (as compared to expected deaths in the general population) was found at any of the locations (Chiazze *et al.*, 1980:526). Additionally, a cohort study of 2429 aerospace workers, found no link to increased risk of respiratory cancer among painters with chromate containing paint exposure (Alexander *et al.*, 1996:1257). However, in a study of 202 deaths among over 40,000 workers employed at

two government-owned aircraft maintenance bases where zinc chromate was used in painting operations, a statistically significant elevation of the proportionate cancer mortality ratio (PCMR) was noted at one base (Dalager *et al.*, 1980:28). No information was available on the smoking status of the workers. Consequently, the authors of the study suggested that smoking could not be discounted as a possible confounding factor given the higher prevalence of smoking among painters as compared to the general population. There is not a clear link between lung cancer and spray painters exposed to  $Cr^{6+}$  due to the inconsistency of the studies.

#### **Particle Deposition in the Lung**

Given that pulmonary carcinoma is the primary adverse health effect from Cr<sup>6+</sup> exposure, the distribution of Cr<sup>6+</sup>–containing particles in the respiratory system is of interest. The size of the inhaled particle affects the location that particle will deposit in the lungs. Specifically, it is the aerodynamic diameter (d<sub>ae</sub>) of a particle or the mass median aerodynamic diameter (MMAD) of an aerosol (i.e., the d<sub>ae</sub> at which half of the mass of an aerosol distribution is less than) that is important in determining the characteristics of the deposition of particles with geometric diameters greater than 0.5 μm (Schlesinger, 1995). Schlesinger lists five main mechanisms responsible for particle deposition in the respiratory system: impaction, sedimentation, Brownian diffusion, electrostatic precipitation, and interception (Schlesinger, 19xx:192). Each of these mechanisms will dominate in different regions of the respiratory system for different sized particles, though impaction is responsible for the majority of deposition in the conductive zone—from the nasal passage or mouth to the terminal bronchioles—for

particles having MMAD greater than 0.5 µm. A typical deposition pattern for an adult male is shown in Figure 1 (Godish, 1991:156).

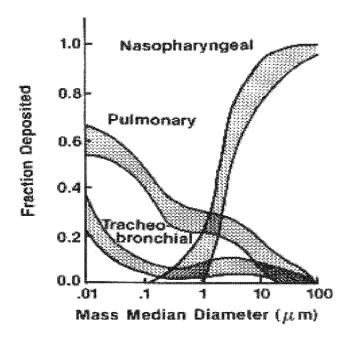


Figure 1. Fractional Deposition of Particles (Task Group on Lung Dynamics, 1966)
USAF Primer Paint

Solvent EP, water EP, and polyurethane primers are the most commonly used primer paints on USAF aircraft surfaces. While the specifications corresponding to all three of primers list SrCrO<sub>4</sub> as the default corrosion inhibiting additive, the chemical and physical properties of these primers differ. This section gives a general description and chromium content of each type of primer used in this study.

#### Solvent-Based Epoxy-Polyamide.

Solvent EP primer is a two-component (base and catalyst) epoxy-polyamide primer. This solvent-borne primer is a low volatile organic compound (VOC). Low VOC, as defined by the Environmental Protection Agency, is a paint that has a VOC

content less than 340 grams per liter at application. The solvent EP primer is the most frequently used primer paint in the Air Force and is known for its solvent and chemical resistance. The mix ratio of solvent EP primer is 3 parts base to 1 part catalyst. The base component contains 25% SrCrO<sub>4</sub> by weight (w/w) according to the Material Safety Data Sheet (MSDS). Accounting for the mix ratio, densities of components, and mass fraction of Cr<sup>6+</sup> in SrCrO<sub>4</sub>, the expected Cr<sup>6+</sup> content (as Cr<sup>6+</sup>) in the mixed paint is 5.2% (w/w). Since the mixed primer is 72.72% non-volatiles (w/w), the expected Cr<sup>6+</sup> content in the non-volatile fraction of this primer is 7.13% (w/w). Sample calculations of the expected chromium content in mixed paints are given in Appendix A.

#### Water EP.

The water-reducible epoxy-polyamide primer is sometimes substituted as a lower VOC content alternative to the solvent EP primer. The base-to-catalyst ratio is specified as 2:1, with a 4.1-part water reduction (*i.e.*, the mixed paint is—by volume—about 58% water, 28% base component, and 14% catalyst component). Although the base component is 30% SrCrO<sub>4</sub> (w/w) according to the MSDS, the actual chromium content in the mixed primer paint is only 2.54% (w/w). Due to the large water content, the non-volatile fraction of the paint comprises only 34.08% (w/w) of the primer, yielding an expected Cr<sup>6+</sup> content in the non-volatile fraction of the paint at 7.46% (w/w).

#### Polyurethane.

Federal specification TT-P-2760A is a two-component, solvent-borne polyurethane primer. This elastomeric, low VOC primer has excellent flexibility characteristics. This primer paint is composed of equal parts (by volume) of base and catalyst components. Accounting for the different densities of the components, the

chromium content in the mixed primer is 3.03% (w/w). Since the mixed primer is 70.84% solids (w/w), the expected  $Cr^{6+}$  content in the solids fraction of this primer is 4.28% (w/w).

Deft, Inc manufactured all three primer paints investigated in this study. A summary of the primer specifications and chromium content is listed in Table 1. (A more detailed listing of primer component specifications is given in excerpts from the product data sheets and MSDS, which can be found in Appendices B, C, and D.)

**Table 1. Summary of Primer Product Codes and Chromium Content** 

	Solvent EP	Water EP	Polyurethane
Military or Federal Specification	MIL-P-23377G Type I, Class C	MIL-PRF-85582C Type I, Class C2	TT-P-2760A Type I, Class C
Manufacture (Deft®) Product Code	02-Y-40	44-GN-72	09-Y-2
Basic Description	Solvent-based, epoxy polyamide	Water-reducible, epoxy polyamide	Solvent-based, elastomeric polyurethane
Batch Numbers Tested	Base: 46517 Catalyst: 46518	Base: 45699 Catalyst: 45700	Base: 45526 Catalyst: 45527
Mfg Dates	July 2001	April 2001	March 2001
SrCrO <sub>4</sub> Content (w/w) in Base Component	25%	30%	20%
Cr <sup>6+</sup> Content (w/w) in Mixed Primer (as specified)	5.19%	2.54%	3.03%
Percent Non- Volatiles in Mixed Primer	73.10%	34.08%	70.84%
Cr <sup>6+</sup> Content (w/w) in Dry Primer	7.13%	7.46%	4.28%

#### **Regulatory Exposure Limits**

In the United States, the Occupational Safety and Health Administration (OSHA) is the government agency charged with establishing regulations to protect workers from hazardous exposure to chemicals. OSHA accomplishes this primarily through the establishment of permissible exposure limits (PELs). These limits are determined after a thorough review of all relevant scientific data from industry, government, and the research communities. The PEL, a ceiling that can never be exceeded at any time, for chromate is 0.1 mg/m³ (as CrO₃) (29 CFR 1910.1000, Table Z-2). In 1993, however, OSHA was petitioned by the Oil, Chemical, and Atomic Workers International Union (OCAW) and Public Citizen's Health Research Group (HRG) for an emergency temporary standard (ETS) to reduce limits to occupational exposures to Cr<sup>6+</sup>. Although the request for an ETS was denied, it prompted OSHA to offer a proposed rule which would replace the current PEL with an eight-hour, time-weighted average (TWA) of 0.0005 mg Cr<sup>6+</sup>/m³ (OSHA, 1996).

This proposed limit is identical to the current eight-hour Threshold Limit Value (TLV-TWA) set by the American Congress of Governmental Industrial Hygienists (ACGIH). ACGIH is a private organization of professionals that establishes exposure limits intended to protect workers from adverse health effects. Although limits set by ACGIH are not legally enforceable, OSHA and industry often reference ACGIH guidelines. Like OSHA, ACGIH relies on the most relevant scientific data on the health effects of exposure levels to establish a limit for a chemical. Much of the information regarding the exposure to Cr<sup>6+</sup>-containing compounds is based on the chromium

production, chromium-pigment production, and chromium plating industries (Finley *et al.*, 1992:170).

#### **Particle Kinetics**

In order to understand the distribution of chromate in the overspray of aircraft paint, it is necessary to characterize the nature of the overspray. A brief review of the atomization process that the liquid paint must undergo reveals a number of parameters that may affect the mean particle size, the size distribution of the paint particles, and the bias in the Cr<sup>6+</sup> content over the range of particle sizes. This section describes the atomization process as well as some of the key parameters relevant to spray painting.

#### Atomization Overview.

In general, the atomization process of spray painting, like all types of atomization, involves the disintegration of a liquid into drops (*i.e.*, the dispersed phase) suspended in a gaseous media (*i.e.*, the continuous phase) due to an acting force (Bayvel and Orzechowski, 1993:37). As the liquid stream of paint emerges from the nozzle of the gun, external forces, mostly from an air stream applied at the nozzle exit, and turbulent properties of the fluid begin to break the jet into thin ligaments, which eventually further disintegrate into drops. Because of this progression of droplet formation, many characteristics of the spray, such as drop size distribution and drop velocity, are functions of both space and time (Lefebvre, 1989:2). Lefebvre notes that these characteristics are influenced by many parameters including the geometry of the spray gun and nozzle, the properties of the air into which the paint is discharged, and the physical properties of the liquid paint (1989:2).

#### Paint Atomization Device.

As sprays can be produced by a number of different atomization processes, the atomization devices will differ in geometry, operational design, and operational settings to produce sprays with various characteristics. In the case of spray painting, the nozzle and air cap of the spray gun can be classified as an airblast atomizer. In this type of atomizer, the paint is discharged through the nozzle into a thin stream. The air cap, which is mounted at the end of the paint nozzle, has two protrusions on the outer edge

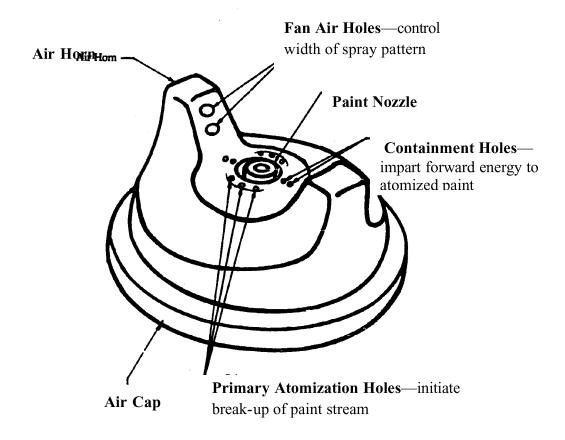


Figure 2. Illustration of Typical Air Cap (Kwok, 1991)

called air horns. Closer to the center of the cap, two sets of holes can be found from which compressed air jets are formed. The closest sets of jets, the primary atomization holes, are on opposing sides of the nozzle as shown in Figure 2. The primary atomization

holes release high volume jets of air, which shear the liquid stream to begin atomization. The paint stream is broken into thinner streams that move in an outward direction as the energy from the air has changed the original vector of the paint stream. The outer pairs of holes at the base of each air horn are the containment holes. The air from the containment holes will send the particles in an elongated elliptical pattern towards the target (Kwok, 1991:5). The adjustable volume of air released from the fan holes serves as an additional control on the pattern width of the paint. The number, layout, and size of atomization and containment holes will vary in different air caps.

#### Liquid Properties.

The properties of the paint—primarily, density, surface tension, and viscosity—will also determine particle size distribution. Theoretically, mass flow rate will increase proportionally with the square root of the liquid density. However, the change in density of a liquid will almost always result in a change in the other properties of a liquid which also influence particle size distribution (Lefebvre, 1989:11).

Surface tension is related to the force with which the liquid will resist the change in surface area (*i.e.*, the formation of new surface due to atomization). Thus, the minimum energy required to atomize a given volume of liquid is equal to the surface tension multiplied by the ratio of atomized surface area to original surface area (Lefebvre, 1989:11). Given the difficulty in quantifying the increase in surface area, the effects of viscosity on flow and spray characteristics may be more beneficial to monitor.

The influence of paint viscosity on particle distribution can be seen prior to the atomization process. A more viscous liquid will prevent the development of instabilities in the jet considering an increase in viscosity will lower the Reynolds number.

Therefore, with a more viscous liquid, the disintegration of the liquid jet will occur at lower energy farther from the nozzle, resulting in larger droplet diameters (Lefebvre, 1989:11). Furthermore, the liquid flow rate through the nozzle will usually decrease as viscosity increases. However, the diameter of the droplets produced by airblast atomizers does not vary much due to a change in viscosity (Lefebvre, 1989:14). Lefebvre claims that the influence of viscosity on drop sizes is more pronounced in pressure atomizers that have a higher liquid velocity relative to airblast atomizers. However, experimental evidence contradicts this logic. By increasing viscosity of the paint from 57 centistokes (measure of a materials kinematic viscosity equal to  $mm^2/s$ ) to 106 centistokes, the MMAD increased slightly from 38  $\mu$ m to 46  $\mu$ m (Kwok, 1991:192). Although an increase in pressure caused an increase in average particle size, Kwok found that the shape of the distribution of the collected overspray was not influenced by a change in viscosity.

#### Air-to-Paint Ratio.

Given the liquid properties of a paint and design parameters of a spray gun, only the operational settings are likely to affect the atomization quality of the paint. Of the operational settings, the ratio of air mass flow to paint mass flow through the gun has the greatest influence on the degree of atomization (Kwok, 1991; Carlton and Flynn, 1997). Kwok observed that increasing the A/P ratio resulted in smaller particles as well as more overspray (*i.e.*, lower transfer efficiency). Since increasing the A/P ratio changes the magnitude of forces responsible for atomization, it may influence the Cr<sup>6+</sup> content of paint particles as well. It is worth noting that while increasing the A/P ratio will always provide for more atomization (*i.e.*, smaller particles), the effect that this parameter has on

transfer efficiency—defined as the percentage of mass of paint sprayed that remains on target—depends on other factors. Since transfer efficiency is a function of the Stokes number, which is proportional to the square of the particle diameter times the particle's velocity, the change in the velocity of the particle is important to determine if the particle will impact the target (Kwok, 1991).

#### Secondary Atomization.

With the basic theory of atomization described above, it is important to mention the concept of secondary atomization. An understanding of the process by which larger particles, created from the initial atomization, are subsequently atomized into smaller particles is helpful in order to gain insight about possible explanations of a bias in the  $Cr^{6+}$  content toward larger overspray particles. The likelihood of a suspended liquid drop breaking up in air largely depends on the Weber number of that drop exceeding its critical Weber number (We>We\*) (Bayvel and Orzechowski, 1993:70; Lefebvre, 1989).

$$We^* = \frac{8}{C_D} \tag{1}$$

where

 $C_D = drag$  coefficient of the drop,

and

$$We = \frac{\rho_L V_L^2 D}{\sigma}$$
 (2)

where

 $\rho$  = liquid density

 $V_L$  = liquid velocity in outlet orifice

D = drop diameter

 $\sigma$  = surface tension of liquid

Criteria other than the critical Weber number may also determine the degree of secondary atomization, such as the type of load acting on the initial drop, liquid viscosity, time of disintegration, and drop diameter (Bayvel and Orzechowski, 1993: 74).

In general, a few different mechanisms have been observed that describes the disintegration of a drop. The three most common mechanisms that describe the formation of smaller drops from a larger drop are the "parachute"-type disintegration mechanism, the chaotic mechanism, and the shear mechanism. The major difference in the various processes is the orientation of the deformation of the spherical drop. A drop that is flattened, forming an oblate ellipsoid, may stretch to the point to which it forms a ring-like shape that disintegrates into several smaller drops (a.k.a. "parachute"-type disintegration or bag mechanism). Bayvel and Orzechowski describe a particular scenario involving several parachutes developing simultaneously on a single drop—the chaotic mechanism. A drop, which becomes elongated into a cigar-shape, may develop into ligaments from which smaller drops are sheared—the shear mechanism. Additionally, local deformations may develop on a drop that result in the occurrence of the shear mechanism or the burst mechanism—a situation where "shear-type" disintegration proceeds very rapidly (Bayvel and Orzechowski, 1993:72; Lefebyre, 1989; 30).

Understanding possible mechanisms responsible for the atomization of particles may help explain the disproportionate decrease in the  $Cr^{6+}$  content in smaller particles in the overspray. Varying the A/P ratio in this study should vary the forces involved in secondary atomization. The effect of these forces on the  $Cr^{6+}$  content in a given particle

size range may help explain possible mechanisms responsible for the bias in  $Cr^{6+}$  as a function of particle size.

#### Particle Collection

Since part of the motivation behind this research is to characterize the relative quantity of Cr<sup>6+</sup> in various sizes of paint particles, it was desirable to select a method of particle collection that would separate a particle stream according to size in a manner similar to the mechanism of particle deposition in the human respiratory system. While many different collection techniques that rely on mechanisms such as gravitational settling and thermal precipitation have been used to collect and analyze particle distributions, most collection devices are based on the mechanism of inertial impaction (Marple *et al.*, 1993:206). Inertial impaction—not simply particle size—is the most important factor determining particle deposition. Not only is impaction responsible for a particle depositing on the target surface of painting operations, impaction is responsible for most particle deposition is the lungs. Impactors (single- or multi-stage) have become the standard collection instrument used in the determination of particle distributions of paint overspray (Kwok, 1991; Chan *et al.*, 1986; Ackley, 1980).

The principle of inertial classification is based on categorizing particles based on their inertia. Basically, a particular flow condition is set so that a particle entering a collection device will either possess enough inertia so that it escapes the trajectory of the gas streamline or possess too little inertia so that it remains in the gas streamline.

Particles that break free of the gas flow will continue in a new trajectory until they impact on a collection plate.

Cascade impactors, which are used as the particle collection device in this study, contain multiple numbers of collection plates called stages. Each subsequent stage in these impactors has smaller inlet jets that create progressively greater velocities of the particle-laden gas stream, which allow for impaction of smaller particles that possessed less inertia in the previous stage. (A schematic drawing of a typical cascade impactor is shown in Figure 3. As Figure 3 illustrates, a stage is consists of the area from the inlet nozzle to the impaction plate on which the nozzle flow impinges (Hinds, 1982:120)).

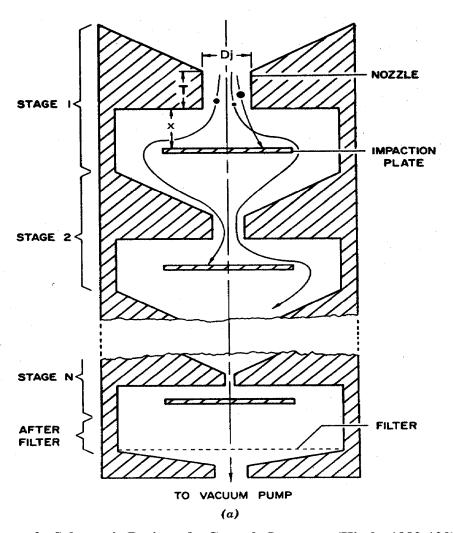


Figure 3. Schematic Design of a Cascade Impactor (Hinds, 1982:120)

Each stage of the cascade impactor collects particles in a specific size range based on aerodynamic diameter. The nominal measurement of that stage is usually referred to as the effective cutoff diameter (ECD $_{50}$ ) or, simply, cutoff size. In operation, the

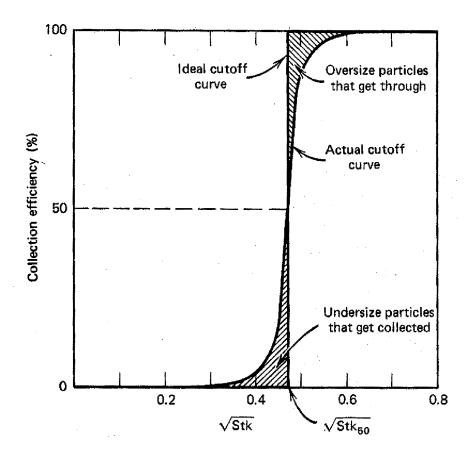


Figure 4. Actual and Ideal Impactor Cutoff Curves (Hinds, 1982:117)

aerodynamic diameter of the particles collected on a particular stage is assumed to be larger than the  $ECD_{50}$  of that stage and smaller than the  $ECD_{50}$  of the previous stage (Lehtimaki and Willeke, 1993:117). The  $ECD_{50}$  of a stage is defined by the aerodynamic diameter of a particle that is captured with 50% efficiency by that stage—in other words, the lower cutoff size. As displayed by Figure 4, it can be assumed that, for this particle size, the "mass of particles larger than the cutoff size that get through (upper shaded area)

equals the mass of particles below the cutoff size that are collected (lower shaded area)." (Hinds, 1982:117).

As shown in Figure 4, the cutoff size is often recorded in terms of the square root of a dimensionless parameter, the Stokes number (Stk) defined as:

$$\sqrt{Stk} = \sqrt{\frac{\rho_p C_c d_p^2 U}{9 \mu W}}$$
 (3)

where

 $\rho_p$  = particle density

Cc = slip correction

U = average air velocity at the nozzle exit  $(=Q/\pi(W/2)^2)$  for a round nozzle

 $d_p$  = particle diameter

 $\mu = air dynamic viscosity$ 

W = nozzle diameter

Q = volumetric flow rate through the nozzle

To calculate the cutoff sizes for each stage rearrange the equation as shown:

$$d_{50} = \sqrt{\frac{9\eta W}{\rho_{\scriptscriptstyle p} C_{\scriptscriptstyle c} U}} \sqrt{St k_{50}} \tag{4}$$

where

 $d_{50} = \text{ECD}_{50}$  for any given stage (Marple *et al.*, 1993:207-11).

In this study, the ECD<sub>50</sub> was calculated for each stage based on the following version of equation (4):

$$ECD_{50} = \sqrt{\frac{(.495)(\mu)(D_j^3)(n)(\pi)}{(Q)(\rho_p)}}$$
 (5)

where

0.495 = Stokes number for round jets (Hinds, 1982:118)

 $D_i^3$  = jet diameter in cm

n = number of jets on the stage

 $\pi = 3.1416$ 

 $Q = \text{volumetric flow in cm}^3/\text{sec}$ 

 $\rho_p$  = partial density for aerodynamic equivalent = 1 g/cm<sup>3</sup>

 $\mu$  = viscosity of air at 22° C = 1.83 x 10<sup>-4</sup> g/cm-sec

This equation is equivalent to equation (4), but re-arranged in terms of volumetric air flow, Q. Also, the nozzle width, W, from equation (4) is replaced by the term  $(D_j^3)(n)$  in equation (5).

#### **Paint Overspray Distribution**

Several studies have sought to characterize the particle size distribution of various types of paint. Although the overspray of different paints produce different particle size distributions, significant reductions in the MMADs of the overspray were reported with increasing atomization pressures. Chan *et al.* (1986) used an air spray gun to generate overspray of high-solids acrylic base coat and clear coat. Spraying with atomization pressures of 30 to 65 psig, they measured the MMAD of the overspray at 6.5 to 4.5  $\mu$ m, respectively. Another study by Ackley (1980) found that lacquer and enamel paint overspray generated from air-blasting had an average MMAD of 6  $\mu$ m. Kwok (1991) found that acrylic enamel paint produces an overspray with MMADs of 30 and 52  $\mu$ m when sprayed with atomization pressures of 68 and 20 psig, respectively (Kwok, 1991).

#### **Previous Overspray Exposure Research**

While research has been done to characterize the distribution of the particles generated from spray painting, little research has explored the chemical composition of the particles within that distribution of particles. Furthermore, many studies have sought to estimate the exposure of workers to paint overspray (Brosseau *et al.*, 1992; Carlton and Flynn, 1997). In these studies, however, the effort was focused on the concentration of particles, not the concentration of a specific chemical, in the worker's breathing zone. It is generally assumed that the exposure hazard is directly proportional to the overall distribution of particles collected without regard to any variation in the chemical

composition of the various particle sizes. Without information available on the chemical composition of different sized particles, it is often assumed that the particles in the overspray are identical in composition to the bulk analysis of the liquid paint.

Few studies have investigated the possible non-uniformity of chemical composition throughout a particle distribution of paint overspray. D'Arcy and Chan investigated the differences between the distribution of overspray aerosol and the distributions of various inorganic species used as pigments or luster enhancers in six different high-solids automotive primer paint (D'Arcy and Chan, 1990). After collecting overspray aerosol using seven-stage cascade impactors, MMADs of the overspray were reported between 2.9 to 9.7 µm. Atomic absorption spectrometry (AAS) was used to determine the mass distribution of aluminum and iron in the overspray collected on the impactor stages. In all samples, the overall MMAD of iron was less than or equal to the MMAD of the total overspray aerosol. However, most aluminum distributions were found to have a higher MMAD than that of the overspray aerosol. They concluded, "using the size distribution of the total overspray aerosol to estimate the respiratory tract penetration of an inorganic species can produce estimates which differ from those based on the chemical distribution of the species," (D'Arcy and Chan, 1990:3877). These results demonstrate the importance of knowing the chemical composition of the overspray particles throughout the entire size distribution to evaluate the true exposure of Cr<sup>6+</sup> to the painter.

### Cr<sup>6+</sup> Content Bias

A previous study explored the  $Cr^{6+}$  content ( $\mu g$  Cr/mg dry paint) in overspray particles as a function of aerodynamic diameter using solvent-based epoxy-polyamide primer paint (Fox, 2000). His data revealed a statistically significant difference in the  $Cr^{6+}$  content in particles with an aerodynamic diameter ( $d_{ae}$ ) less than 2.5  $\mu m$ 

 $(18 \frac{\mu gofCr}{mgof\ drypaint})$  as compared to particles with a d<sub>ae</sub> larger than 2.5  $\mu$ m

 $(70 \frac{\mu gofCr}{mgof\ drypaint})$ . Based on the likely location of deposition of particles with a d<sub>ae</sub> greater than 2.5  $\mu$ m, this finding suggests that a greater mass fraction of Cr<sup>6+</sup> is deposited in the upper respiratory tract than reaches the respiratory zone.

Novy also studied solvent EP primer, using the same military specification paint from two different manufacturers (Deft Inc., Irvine, CA and PRC-DeSoto International, Mojave, CA) (Novy, 2001). Novy was able to demonstrate a more detailed bias in  $Cr^{6+}$  content as a function of aerodynamic particle size. Figure 5 shows the  $Cr^{6+}$  content in dry solvent EP plotted as a function of the impaction stage  $ECD_{50}$ . This study will focus on the  $Cr^{6+}$  content in the particles of solvent EP as well as two other primers not previously investigated for  $Cr^{6+}$  bias.

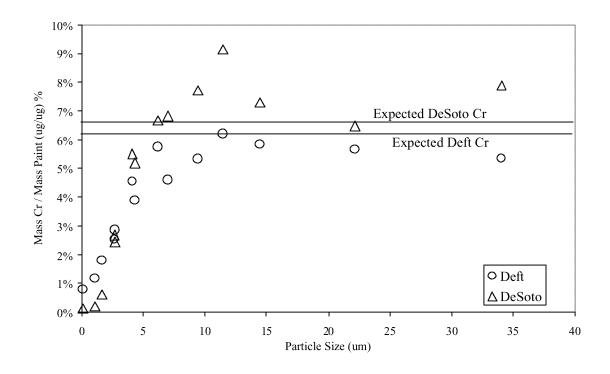


Figure 5. Comparison of Mass Cr per Mass Dry Paint by Manufacturer (Novy, 2001)

#### III. Methodology

#### Overview

This chapter describes the equipment and methods used to generate, collect, and analyze the Cr<sup>6+</sup> content by particle size for three different types of primer paints. Since this study also investigates the possible influence of A/P ratio on Cr<sup>6+</sup> content of paint particles, the spray painting operation parameters are discussed.

#### **Painting Operation**

All painting operations were conducted in a paint booth at the Coatings

Technology Integration Office (CTIO) at Wright-Patterson Air Force Base, Ohio. The

dimensions of this environmentally controlled booth are 10' wide by 14' long by 9' high.

Temperature and humidity were maintained at 24 degrees Celsius (± 4 degrees) and 8%

(± 6%), respectively, for each sampling event. The ventilation inside the booth was set at

100 linear feet per minute—the minimum ventilation rate required by OSHA in paint

spraying operations.

#### Recorded Data.

Thirty-four painting runs were performed: eight with solvent EP, sixteen with water EP, and ten with polyurethane. Each of the paints was prepared in accordance with the respective product data sheets. A summary of the mixing ratios and selected specifications of these paints is given in Table 2.

**Table 2. Primer Preparation Specifications (Deft, 2000)** 

	N	Iix Rat	io		Viscosity
Primer Type	Base	Catalyst	Water	Collection Runs	Test (Ford #4 cup)
Solvent-based, epoxy polyamide	75%	25%	0%	8	20-40 sec
Water-reducible, epoxy polyamide	28%	14%	58%	16	18-22 sec
Solvent-based, elastomeric polyurethane	50%	50%	0%	10	14-24 sec

To generate the paint overspray, a DeVilbiss model JGHV-531 HVLP spray gun, fitted with a DeVilbiss model 46MP air cap, was used. A two-quart, pressure fed paint supply cup was attached to the spray gun. After the paint was prepared, the viscosity of the primer was tested using a Ford #4 cup. Once the viscosity test yielded results within the specifications given in Table 2, the primer was loaded into the paint supply cup. After the spray pattern was checked and the desired nozzle pressure was set, the spray conditions were held constant throughout the paint run.

#### A/P Ratios.

This study examines the effects on the Cr<sup>6+</sup> content among different overspray particle sizes by varying one of the operational parameters of spray painting—the A/P ratio. The nozzle pressure was adjusted on different paint runs so that each of the three types of primers would be tested at two different A/P ratios. A higher A/P ratio was achieved by increasing pressure at the nozzle of the air cap (thus, increasing the air mass flow rate), while maintaining the same pressure to the supply cup (thus, minimizing changes to the paint flow rate). Using calibration data from the gun manufacturer, the

nozzle pressure can be used to estimate an air mass flow rate. Paint mass flow rates were calculated from the measured mass of paint used and the elapsed spray time of each run.

Pressure Settings.

For each of the paints, multiple sampling events were conducted at both a high A/P ratio and a low A/P ratio. Adjusting the wall pressure, which controlled the nozzle pressure, altered this ratio. However, the nozzle pressures were held constant for all runs within each category (i.e., high A/P ratio or low A/P ratio). The pressure in the supply cup (*i.e.*, pot pressure) remained at 14 psig for all sampling events. The pressure settings for all sampling events are documented in Table 3.

Table 3. Pressure Settings and A/P Ratios

			Pressur	re (psig)		Avg.	
Paint Type	High or Low A/P	Number of Sample Runs	Pot	Nozzle	Air Mass Flow Rate (g/s)	Paint Mass Flow Rate (g/s)	Avg. A/P Ratio
Solvent EP	Low	4	14	2.5	5.59	0.76	7.4
Solvent El	High	4	14	8.0	11.0	0.88	12
Water EP	Low	10	14	7.0	9.92	1.16	8.8
vv atel EF	High	6	14	9.0	11.9	1.39	9.9
Polyurethane	Low	6	14	4.0	7.26	0.72	10
1 Ory the thane	High	4	14	8.0	11.0	0.69	16

The nozzle and pot pressures were established based on recommendations from painting technicians and guidelines from the primer product data sheets. As suggested by the conventional definition of HVLP, the nozzle pressure should be held under 10 psig. Product data sheets recommend a minimum of seven psig to establish enough atomization for an acceptable spray, although lower settings are commonly used in the field. The determination of an acceptable spray was based on qualitative assessment of experienced technicians.

#### Paint Mass Flow Rate.

After calculating the air mass flow rate, the A/P ratio can be determined by estimating the paint mass flow rate. The rate of paint flow was determined by two separate methods. In one measurement, the air jets that atomize the paint after exiting the nozzle were shut off. Closing these jets eliminated the source of atomization air without affecting the source of air used to pressurize the paint pot. A small mixing cup was used to collect and weigh approximately 30 mL of paint. The time needed to fill the test cup was used to calculate a mass flow rate.

The other method of testing the paint mass flow rate was conducted by measuring the net mass of the paint sprayed during the sampling event. The mass of paint sprayed was determined by recording the pre-weights and post-weights of the gun, pot, and connected hoses. Dividing the mass of the paint used by the recorded elapsed spray time provides the paint mass flow rate.

The latter method of estimating the paint mass flow rate was used to determine the A/P ratio since it accounts for possible variations in the paint flow rate during sample collection. A difference in the apparent density of particles in the overspray was visually observed towards the end of most sampling events. The former method was used as a quality control check. The average paint mass flow rate for each nozzle pressure is displayed in Table 3.

#### Background Runs.

In addition to the thirty-four painting runs, three sampling runs were conducted without any painting operations. These runs were performed to assess the background concentration of  $Cr^{6+}$  in the paint booth. The collection procedures for these events were

identical to all other sampling events with the exception of paint spraying. The average mass of  $Cr^{6+}$  collected on each stage during the background runs was subtracted from the appropriate stage of each paint run to ensure that the  $Cr^{6+}$  found on a stage of a paint run was from overspray particles.

### **Overspray Collection**

To generate the paint overspray, the HVLP gun was aimed at a cardboard target and the overspray was allowed to draft toward the cascade impactors. This 15"x15" target was placed perpendicular to the direction of paint flow, eight inches from the tip of the gun's nozzle as depicted in Figure 6. Furthermore, the centerline of the paint stream

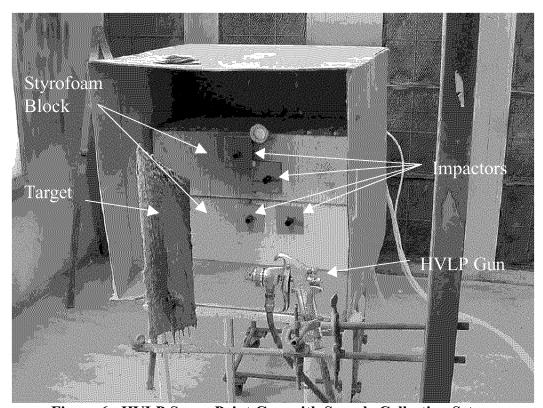


Figure 6. HVLP Spray Paint Gun with Sample Collection Set-up

from the gun to the target was 12" from the front edge of the cardboard enclosure that contained the sample collection equipment. The enclosure was used to slow the velocity of the overspray particles, thus increasing the number of particles collected. Booth ventilation directed the overspray toward the cardboard enclosure located downdraft of the HVLP gun. The face of the enclosure was 27" wide by 25" high. The face of the block was recessed 13.5" from the edge of the enclosure—25.5" from the centerline of the paint stream leaving the HVLP gun. Four cascade impactors (manufactured by In-Tox Products) were used for overspray collection—two large-particle size range impactors and two small-particle size range impactors. The placement of the impactors is shown in Figure 7.

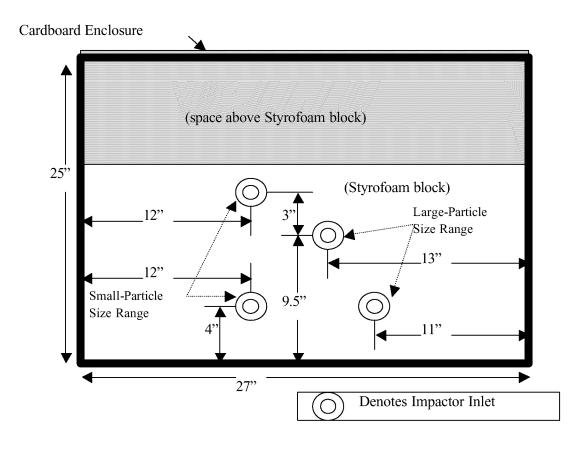


Figure 7. Impactor Layout (Not to Scale)

The flow rate through the impactors was calibrated prior to the start of the sampling run. After each sampling event, the calibrations were checked. All post-calibration air flow readings were within 1% of the pre-calibrations. All calibrations were performed using a Gilibrator Airflow Calibration System #800286 with a high-flow bubble chamber.

After the impactors were calibrated, the trigger on the HVLP gun was held to a fully open position with a plastic zip tie for the duration of the sampling period. The durations of the sampling events varied from approximately 6 to 30 min. These times varied mostly due to the varying volumes (640 to 1000 mL) used during different painting runs. The volume of paint was varied to optimize sample collection without overloading the impactors.

#### Particle Size Ranges.

Four seven-stage cascade impactors were used to collect primer overspray particles and separate them into discrete size ranges (see Tables 4 and 5) based on their aerodynamic diameter. The  $ECD_{50}$  was calculated for each stage based on equation (5). In equation (5), the volumetric air flow rate through the impactors is the only variable able to affect the  $ECD_{50}$  of a stage. For this reason, the air flow rate was calibrated for each impactor to establish the  $ECD_{50}$  values. The large-particle size range impactors were calibrated at 8.000 (+/- 0.050) L/min; while, the small-particle size range impactors were set with a flow rate of 18.00 (+/- 0.10) L/min. The calculated  $ECD_{50}$  values at the designed flow rates for the impactors used in this study are given in Tables 4 and 5.

Table 4. Small Particle Size Range Impactor (18 L/min)

Stage #	1	2	3	4	5	6	7
Number of Jets per Stage	1	2	3	4	6	9	12
Average Jet Diameter (cm)	1.1125	0.0635	0.4003	0.2636	0.1679	0.1082	0.07315
ECD <sub>50</sub> (μm) (18 L/min)	11.4	7.0	4.3	2.6	1.6	1.0	0.7
Particle Size Range of Stage	>11.4	7.0 to	4.3 to	2.6 to	1.6 to	1.0 to	0.7 to
		11.4	7.0	4.3	2.6	1.6	1.0

Table 5. Large Particle Size Range Impactor (8 L/min)

Stage#	1	2	3	4	5	6	7
Number of Jets per Stage	1	1	2	2	3	4	6
Average Jet Diameter (cm)	1.7582	1.3208	0.7884	0.5636	0.3914	0.2692	0.1788
ECD <sub>50</sub> (μm) (8 L/min)	34.1	22.2	14.5	9.5	6.2	4.1	2.7
Particle Size Range of Stage	>34.1	22.2 to	14.5 to	9.5 to	6.2 to	4.1 to	2.7 to
		34.1	22.2	14.5	9.5	6.2	4.1

Figure 8 illustrates the particle size ranges collected by stage for both types of impactors. This demonstrates the wide range of particle diameters collected with two different impactor designs, with an overlap of several stages for comparison between the two impactors. Note that there is no upper bound on the size of particles collected on the first stage of both impactors. On each impactor, the seventh stage is followed by a back filter (0.8-µm pore size, not shown in figure 8), which collects most particles less than the ECD<sub>50</sub> of the seventh stage.

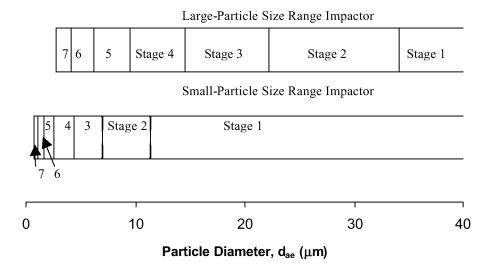


Figure 8. Particle Size Range by Stage

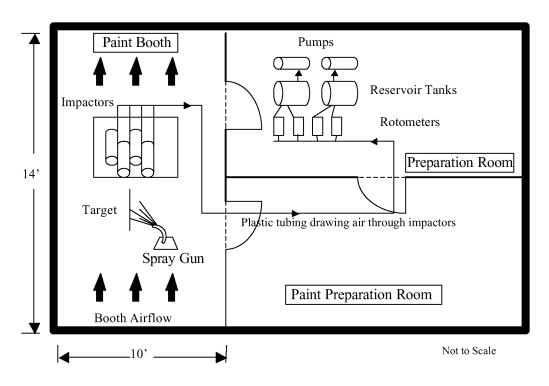


Figure 9. Sampling System Layout at CTIO Paint Booth

### Sampling System.

Figure 9 illustrates the layout of the sampling system. Two Gast pumps provided the vacuum source for airflow through the impactors. Each pump supplied two impactors, on which individual valves equipped with rotameters regulated the airflow rates separately. A five-gallon receiving tank was attached in series to each pump (between the rotometer and the vacuum pump) as a means of balancing air flow fluctuations. Figure 10 shows the air flow control system for the impactors, which was located outside of the paint booth since the pumps are an ignition source and the paint poses a fire hazard. The hoses from the rotometer inlets continue under the booth door with the plastic tubing connecting to the impactors.

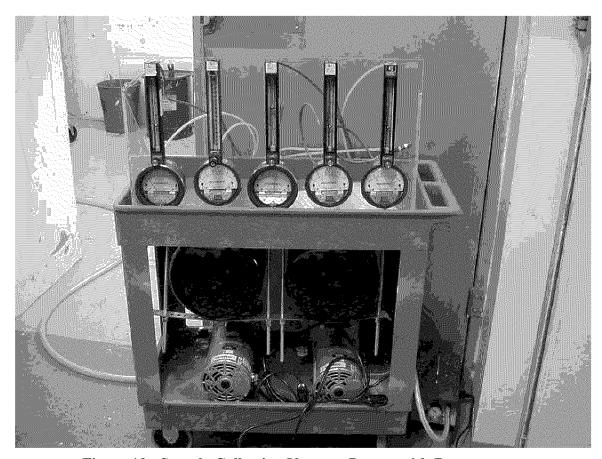


Figure 10. Sample Collection Vacuum Pumps with Rotometers

#### **Sample Preparation**

After particles were collected, samples containing the captured paint particles were dried, weighed, and digested in preparation for analysis. Since each separate collection plate (seven stages plus one back plate per impactor) represents an individual sample, each painting run resulted in 16 individual samples (8 high range and 8 low range) that required preparation. This section documents the procedures followed for each sample.

#### Sample Substrates.

Overspray particles were collected on 0.22-µm (pore-size) cellulose ester filters (CEFs), manufactured by Millipore. These CEFs covered the entire surface area of the impaction plates, ensuring efficient capture of particles entering the impactors. The ease of removal of these filters from the impactors further improved the efficient transfer of collected particles into a sample solution for analysis. Additionally, CEFs are digestible, thus, eliminating the need for additional processing to remove collected sample from the filter before digesting.

#### Analytical Mass Determination.

Each CEF was weighed before and after the sampling event so that the dry mass of collected paint particulates could be determined for each stage. All weighing operations were conducted inside an air-tight glove box (which contained Drierite anhydrous calcium sulfate). To minimize fluctuation due to non-evaporated water and solvent content, each CEF was stored in the sealed glove box for 24 hours before taking the pre-paint mass and post-paint mass of the CEF. After weighing, the glove box was opened only for the brief time required to exchange a tray (one tray per painting run) of

filters—less than ten seconds per tray. The glove box was never opened during the 24-hour drying periods leading up to the weighing or during the weighing operations.

All weighing operations were performed using a Mettler-Toledo microbalance model MT5 (precision 0.001 mg). Each sample was weighed and recorded in triplicate. Furthermore, each sample was passed through a Haug U-electrode ionizer model PRX-U prior to placing in the weighing chamber to reduce the effects of static charge carried by the filter.

#### Sample Digestion.

Before a sample could be analyzed, the solid particles and filter must be digested into a liquid sample. Each paint sample (i.e., CEF and collected paint) was placed in a Teflon digestion vessel along with trace-metals grade, 70% (w/w) nitric acid and digested in an OI analytical microwave. 5.0 mL of the nitric acid were added to most samples, but due to the large mass of paint collected on some first-stage samples, as much as 20 mL of nitric acid was added for complete digestion. Sealed pressure vessels were loaded into carousels and digested according to a pressure-controlled program based on NIOSH method 7082—used for digestion of paint chips. Pressure was held at a minimum of 70 psig so that a minimum temperature of 140 degrees C was maintained for at least 20 min. Table 6 details the digestion program used.

**Table 6. Sample Digestion Program** 

Stage	Power	Set Point	Dwell Time	Max Time
Stage	(%)	(psig)	(mm:ss)	(mm:ss)
1	75	20	02:00	03:00
2	100	70	20:00	30:00
3	0	0	02:00	02:00

#### Sample Dilution.

Following digestion, vessels were allowed to cool before opening. Once opened, the contents of the Teflon vessels were transferred into a 30-mL high-density polyethylene (HDPE) sample bottle. The Teflon vessels were triple rinsed with a total of 20 mL of deionized water. This rinsate was transferred to the HDPE bottle, yielding approximately 25-mL of sample for analysis.

More precise sample volumes were calculated based on the mass of each liquid sample. The mass of the liquid in each HDPE bottle was measured with a Mettler-Toledo balance model AB204-S (precision 0.1 mg). Based on the loaded filter weight and the densities of the 70% nitric acid and deionized water, the volume of sample contained in each HPDE bottle was calculated:

Sample Volume 
$$(mL) = \frac{m_{sample} - m_{filter+paint} - (V_{70\%} \cdot \rho_{70\%})}{\rho_{di}} + V_{70\%}$$
 (6)

where

 $m_{sample}$  = Net weight of <u>liquid</u> in HDPE sample bottle (g)  $m_{filter+paint}$  = Mass of CEF <u>and</u> paint sample (g)  $\rho_{70\%}$  = Density 70% nitric acid (g/mL)  $\rho_{di}$  = Density of deionized water (g/mL)  $V_{70\%}$  = Volume of 70% nitric acid used for digestion (mL)

Based on these calculated sample volumes and the net mass of the paint collected on each filter, the mass of dry paint per unit volume of the liquid sample is known.

#### Sample Analysis

Analytical determination of the Cr<sup>6+</sup> content in each sample was performed on a GBC Avanta atomic absorption spectrometer (AAS). This AAS is capable of sample

analysis using either a graphite furnace or flame method. The graphite furnace was used for analysis of liquids expected to contain less than one part per million (ppm) chromium; the flame method was used to analyze liquid samples expected to contain between 1 and 15 ppm. When necessary a sample was diluted, either manually or automatically (by the AAS), so that the chromium concentration was within the calibration range of the method.

For the graphite furnace method, a five-point (7.5, 20, 40, 60, 75-parts per billion (ppb)) calibration (R<sup>2</sup> > 0.98) was performed using the auto-dilution feature on the AAS with a certified 75-ppb Cr standard. Three replicate measurements per sample were performed. A 75-ppb check sample was performed for at least every ten samples analyzed for quality assurance. Each check sample was followed by a sample blank to detect for instrument drift. The auto-dilution feature was able to dilute samples containing more than 75 ppb Cr. For these samples above the calibration range, up to two consecutive 1:4 dilutions were performed using deionized water. Table 7 summarizes the method for the graphite furnace.

Table 7. AAS Graphite Furnace Parameters

Step	Final Temp. (C)	Ramp Time (s)	Hold Time (s)	Gas
Step 1: Inject Sample				
Step 2: Drying	80°	5	10	Argon
Step 3: Charing	130°	30	10	Argon
Step 4: Pyrolysis	1400°	15	15	Argon
Step 5: Atomize/Read	2500°	1.4	1.6	None
Step 6: Tube Clean	2700°	0.5	1.5	Argon

For samples containing chromium concentrations greater than one ppm, an air-acetylene flame method was used. A four-point (1, 5, 10, and 15-ppm) calibration  $(R^2 > 10, and 15-ppm)$ 

0.98) was performed using standards prepared from a certified 250-ppm standard. To ensure consistent atomization, a fuel/oxidant ratio of approximately 1.8/10 was maintained for all samples analyzed by this method. Quality assurance measures identical to those described for the graphite furnace method were implemented for flame atomization using a 10-ppm standard. Since auto-dilution was not available for the flame atomizer, all samples containing over 15 ppm Cr were manually diluted if the sample was above the calibration range for the instrument.

#### **Calculation of Chromium Content in Dry Paint**

Chromium concentrations reported by the AAS ( $\mu g$  Cr/L sample) were divided by the mass of dry paint collected in each sample to calculate the Cr<sup>6+</sup> content

 $(\frac{\mu g \operatorname{Cr}^{+6}}{\mu g \operatorname{dry paint}} x 100\%)$  in different size ranges of particles collected. Equation 7 was used

to calculate the chromium content in dry paint on the CEF for each stage:

$$\frac{\mu g \operatorname{Cr}^{+6}}{\mu g \operatorname{dry paint}} = \frac{C_{AAS} \cdot V_{sample}}{m_{paint}}$$
 (7)

where

 $C_{AAS} = AAS$  reported concentration [corrected for dilution, if necessary]  $(\mu g/L)$ 

 $V_{sample}$  = sample volume [calculated from Equation (6)] (L)

 $M_{paint}$  = Mass of dry paint sample (µg)

#### IV. Results

# Cr<sup>6+</sup> Content per Mass of Dry Paint

Table 8 presents the results of the  $Cr^{6+}$  analysis as a function of particle size range collected (by impactor stage) for the three primer paints. The number of samples in each particle size range (n) and the standard deviation of the sample mean (SD) are listed for each primer type.

Table 8. Average Cr<sup>6+</sup> Content per Mass of Dry Primer Paint

Stage*	Particle Size Range	Solvent-Based Epoxy-Polyamide		Water-Based Epoxy-Polyamide		Solvent-Based Elastomeric Polyurethane				
#	(μm)	Mean %Cr <sup>6+</sup>	SD	n	Mean %Cr <sup>6+</sup>	SD	n	Mean %Cr <sup>6+</sup>	SD	n
	, ,									
S7	0.7 ≤d <sub>ae</sub> < 1.0	0.99%	0.27%	7	0.67%	0.27%	14	0.36%	0.13%	10
S6	1.0 ≤d <sub>ae</sub> < 1.6	1.18%	0.42%	8	0.72%	0.27%	15	0.51%	0.08%	10
S5	1.6 ≤d <sub>ae</sub> < 2.6	1.74%	0.67%	8	1.15%	0.29%	16	0.90%	0.13%	10
S4	2.6 ≤d <sub>ae</sub> < 4.3	2.48%	0.73%	8	2.89%	0.68%	16	1.65%	0.17%	10
L7	2.7 ≤d <sub>ae</sub> < 4.1	2.90%	0.73%	6	1.89%	0.65%	16	1.70%	0.95%	9
L6	4.1 ≤d <sub>ae</sub> < 6.2	4.77%	1.42%	7	4.95%	1.04%	14	2.51%	0.72%	9
S3	4.3 ≤d <sub>ae</sub> < 7.0	4.41%	1.53%	5	4.97%	0.67%	14	2.79%	0.39%	10
L5	6.2 ≤d <sub>ae</sub> < 9.5	6.17%	0.47%	5	6.50%	1.15%	15	3.77%	0.94%	10
S2	7.0 ≤d <sub>ae</sub> < 11.4	7.09%	1.65%	8	6.56%	1.36%	16	3.72%	0.70%	10
L4	9.5 ≤d <sub>ae</sub> < 14.5	7.20%	0.98%	6	6.67%	1.36%	14	3.86%	0.71%	9
L3	14.5 ≤d <sub>ae</sub> < 22.2	5.17%	0.57%	6	6.27%	1.21%	13	3.76%	0.74%	9
L2	22.2 ≤d <sub>ae</sub> < 34.1	4.45%	1.37%	6	5.57%	1.22%	14	3.60%	1.06%	10
L1	34.1 ≤d <sub>ae</sub>	6.94%	1.99%	6	6.03%	1.29%	15	4.34%	0.51%	9

<sup>\*</sup>S denotes small-particle size range impactor; L denotes large particle-size range impactor

The results of the analysis of the samples collected on the first stage of the small particle size range impactor (S1) were not reported. The mass of paint particles collected on the filters from S1 was so large that complete digestion could not be reliably accomplished.

Figures 11a-c display the mean percent Cr<sup>6+</sup> plotted against the particle size range collected. Since some stages from the small and large particle size range impactors overlap, the stages for both impactor types are plotted in two different shades. Dark areas

represent stages of the small particle size range impactors; light areas are for the large particle size range impactor stages. The vertical range of percent  $Cr^{6+}$  plotted covers the 95% confidence interval about the mean. A solid line is included on each figure to show the expected  $Cr^{6+}$  content per mass of dry paint for the corresponding type of primer (as reported in Table 1). The particle size range collected by the largest stage displayed on these figures has no theoretical upper limit, although the figures are arbitrarily trunc ated at 40  $\mu$ m. Nevertheless, it is unlikely that an appreciable number of larger particles entered the impactor as these particles would have impacted on the cardboard target.

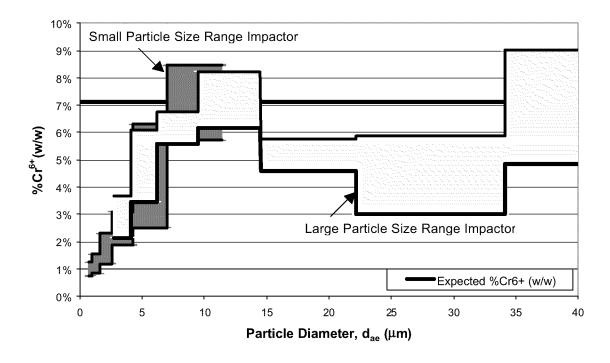


Figure 11a. Mass of Cr<sup>6+</sup> per Mass of Dry Paint: Solvent-Based Epoxy-Polyamide

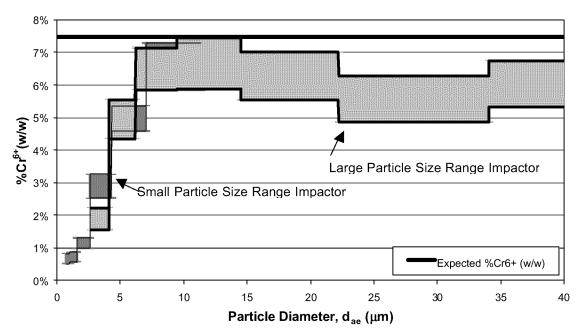


Figure 11b. Mass of Cr<sup>6+</sup> per Mass of Dry Paint: Water-Based Epoxy-Polyamide

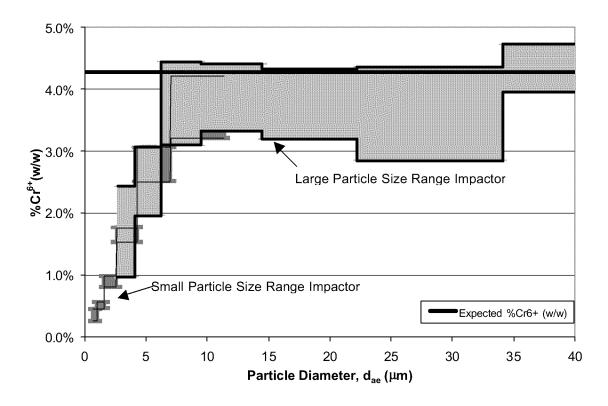


Figure 11c. Mass of Cr<sup>6+</sup> per Mass of Dry Paint: Solvent-Based Elastomeric Polyurethane

# A/P Ratio Influence on Cr6+ Content

Figures 12a-c show the mean percent  $Cr^{6+}$  plotted against the  $ECD_{50}$  for each impactor stage for the subsets of both the high and low A/P ratios. The percent  $Cr^{6+}$  is plotted as a function of the  $ECD_{50}$  value of each impactor stage to clearly compare the trends. The error bars on these figures enclose the 95% confidence interval about the mean percent  $Cr^{6+}$ . The data points for the high A/P ratio data series are slightly offset to the right so that the error bars for the two series of data are easier to distinguish.

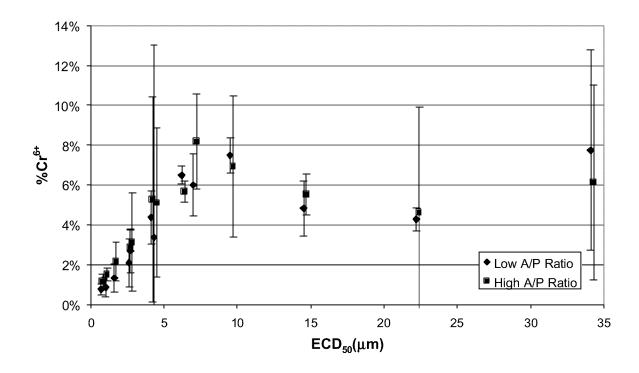


Figure 12a. Comparison of Mean Percent Cr<sup>6+</sup> for Different A/P Ratios: Solvent-Based Epoxy-Polyamide (Bars represent 95% confidence interval about mean)

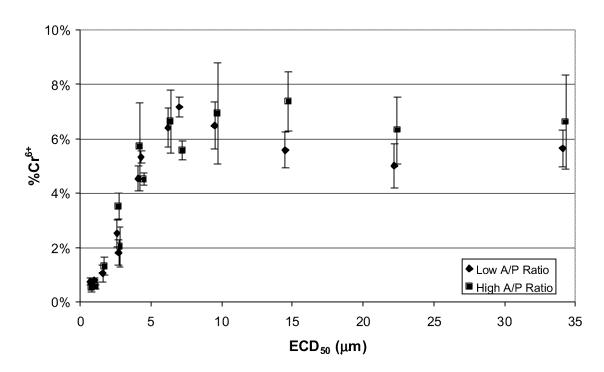


Figure 12b. Comparison of Mean Percent Cr<sup>6+</sup> for Different A/P Ratios: Water-Based Epoxy-Polyamide (Bars represent 95% confidence interval about mean)

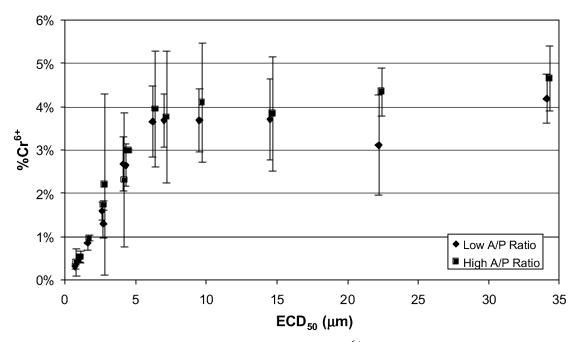


Figure 12c. Comparison of Mean Percent Cr<sup>6+</sup> for Different A/P Ratios: Solvent-Based Elastomeric Polyurethane (Bars represent 95% confidence interval about mean)

The means of the high and low A/P ratio categories were compared for each stage using a paired Student's t analysis. For both epoxy-polyamide primers, the mean percent  $Cr^{6+}$  for at least two stages were found to be statistically different (at the  $\alpha=0.05$  level). However, due to the small sample sizes and the lack of any repeatable trend, these data suggest that practical variations in the A/P ratios do not impact the  $Cr^{6+}$  bias to any appreciable degree.

# Comparison of Cr<sup>6+</sup> Content Bias to Previous Study

Figure 13 compares the  $Cr^{6+}$  content bias found in the solvent-based epoxy-polyamide primer paint during this study to the  $Cr^{6+}$  content bias reported by Novy (2001) on the same military specification primer from the same manufacturer. The agreement of the data indicates a high degree of repeatability between these studies. The error bars shown in Figure 13 contain the 95% confidence interval about the mean.

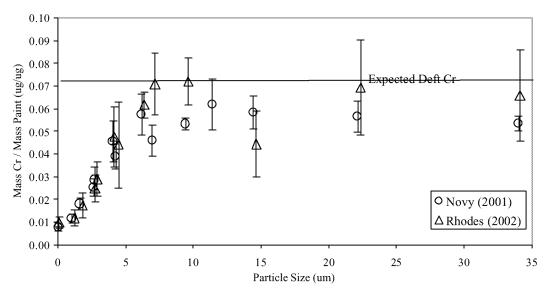


Figure 13. Comparison of Mass of Cr<sup>6+</sup> per Mass of Dry Paint by Study

#### V. Discussion

## Cr<sup>6+</sup> Content Bias in Different Primers

The mean percent  $Cr^{6^+}$  of the largest particle sizes collected closely match the expected  $Cr^{6^+}$  content in the dry paint. For all three primers, the  $Cr^{6^+}$  content per mass of dry paint in the last five stages ( $d_{ae} < 7.0 \ \mu m$ ) of the small particle size range impactor and the last two stages ( $d_{ae} < 6.2 \ \mu m$ ) of the large particle size range impactor was significantly less than the expected  $Cr^{6^+}$  (at the  $\alpha$ =0.05 level of confidence). With the exception of the water EP primer, the mean  $Cr^{6^+}$  content of the largest stage ( $d_{ae} > 34.1 \ \mu m$ ) was within 2% of the expected value. This observation suggests that the  $Cr^{6^+}$  content in the larger particles is similar to that of the solids fraction of the homogeneous, mixed primer paint.

The largest particles collected of the water-based epoxy-polyamide primer contained less than the expected amount of  $Cr^{6+}$  per mass of dry paint (at the  $\alpha$ =0.05 level of confidence). This may be due to water content in the collected paint particles that did not evaporate during the drying phase. Water-based primers have been noted for the slow removal of water during the curing process (Mitchell, 2002). The high reactivity of water with the epoxy resins may have caused some of the water to remain in the dry paint, which would add mass to the dry paint, thus lowering the measured percent  $Cr^{6+}$  in the dry paint. Nevertheless, the overall trend of the  $Cr^{6+}$  content in the water EP primer followed that of the other two primers. This bias is expected to be less prevalent with smaller particles since water may be able to escape more easily with the larger surface area to volume ratio.

## Influence of A/P Ratio on Cr6+ Content

The variation of the A/P ratio during paint atomization did not have a discernable effect on the Cr<sup>6+</sup> content of the particles. Testing over a greater range of A/P ratios may have produced different results. However, the range of A/P ratios tested in this study reflects the normal operating conditions in the field. Higher or lower A/P ratios would have produced unacceptable spray patterns or would not have been possible with an HVLP gun.

# Implications of Cr<sup>6+</sup> Content Bias

The repeatable, disproportionate decrease in  $Cr^{6^+}$  in the smaller particles of the primer overspray has implications on the health hazards to aircraft spray painters. Considering the dependence of particle size on the penetration depth of an airborne particle in the respiratory system, the bias in  $Cr^{6^+}$  content may lead to a lower estimate of  $Cr^{6^+}$  exposure than previously thought. Since smaller particles tend to deposit deeper in the lungs, less  $Cr^{6^+}$  per mass of material inhaled is delivered than expected if one assumes a uniform distribution of  $Cr^{6^+}$  throughout the particle size distribution of the overspray. The results presented here indicate that particles capable of reaching the alveolar sacs in the pulmonary region of the lungs—generally  $d_{ae}$ <2.5 $\mu$ m—have only about one-third of the  $Cr^{6^+}$  that is present in the larger particles.

Figures 14a-16b show an estimate of the  $Cr^{6+}$  deposition in the three main regions of the lung—nasopharyngeal, tracheobronchial, and pulmonary—based on the mass of  $Cr^{6+}$  collected for each type of primer. A pair of stacked bars are plotted for each region of the lung—one representing the experimentally determined mass of  $Cr^{6+}$  collected (the left bar of each pair) and one representing the mass of  $Cr^{6+}$  in the collected mass of dry

48

paint based on the assumption that Cr<sup>6+</sup> is uniformly distributed throughout all particle sizes in the primer overspray (the right bar of each pair). The relative contribution of particles from each impactor stage is shown in the bars. The stages are stacked with those representing largest particles on the bottom and smallest particles on the top. These figures are based assumed probabilities of the median size particle of a stage depositing in each region of the lung. The assumed probabilities were taken from Figure 1.

Figures 14a-16b demonstrate the impact that the disproportionate decrease of  $Cr^{6+}$  in smaller particles has on the overall mass of  $Cr^{6+}$  delivered to each region of the lung. The impact is more pronounced in Figures 14a, 15a, and 16a since these represent data from the small particle-size range impactors. In general, the areas corresponding to stages representing larger particle sizes do not change from the left bar to the right bar since the  $Cr^{6+}$  content closely matched the expected  $Cr^{6+}$  content in dry paint.

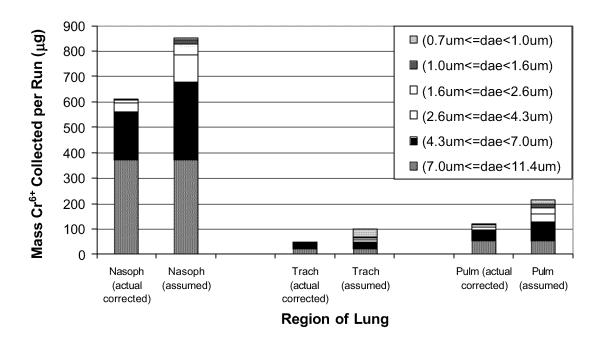
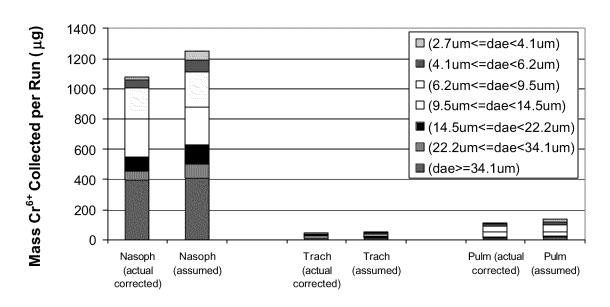


Figure 14a. Cr<sup>6+</sup> Deposition in Lung: Solvent-Based Epoxy-Polyamide (Small Particle-Size Impactor)



**Region of Lung** 

Figure 14b. Cr<sup>6+</sup> Deposition in Lung: Solvent-Based Epoxy-Polyamide (Large Particle-Size Impactor)

Note: -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary

-Order of areas in bars matches order listed in legend (top to bottom)

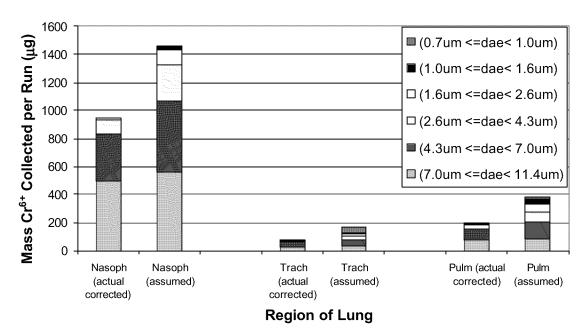


Figure 15a. Cr<sup>6+</sup> Deposition in Lung: Water-Based Epoxy-Polyamide (Small Particle-Size Impactor)

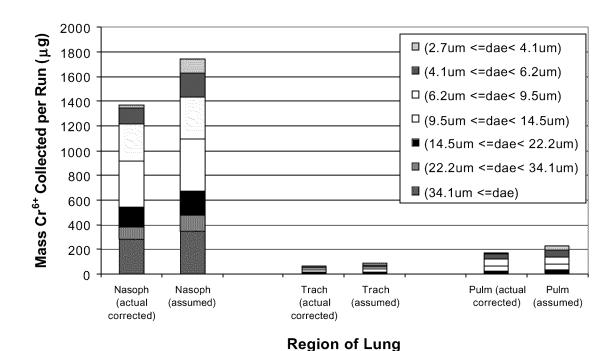


Figure 15b. Cr<sup>6+</sup> Deposition in Lung: Water-Based Epoxy-Polyamide (Large Particle-Size Impactor)

 $Note: \ -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary$ 

-Order of areas in bars matches order listed in legend (top to bottom)

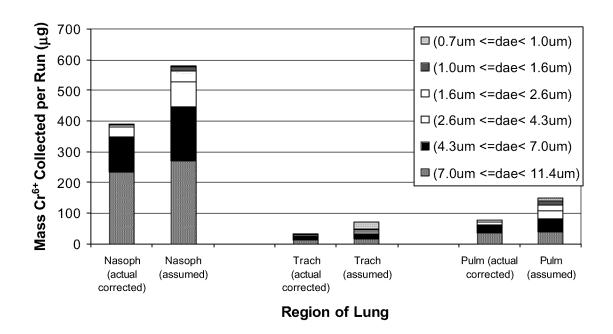


Figure 16a. Cr<sup>6+</sup> Deposition in Lung: Solvent-Based Elastomeric-Polyurethane (Small Particle-Size Impactor)

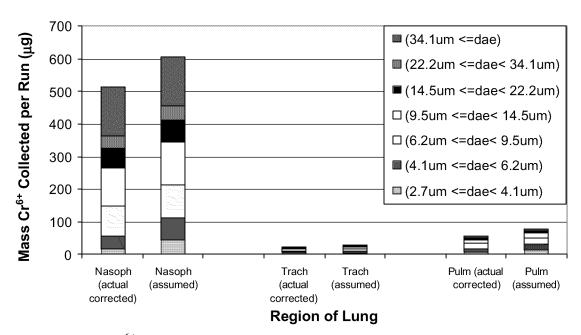


Figure 16b. Cr<sup>6+</sup> Deposition in Lung: Solvent-Based Elastomeric-Polyurethane (Large Particle-Size Impactor)

Note: -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary -Order of areas in bars matches order listed in legend (top to bottom)

As noted by LaPuma *et al.*, the  $Cr^{6+}$  bias may also merit the examination of practices used to estimate the fugitive emissions of  $Cr^{6+}$  from industrial paint booths (LaPuma *et al.*, 2001:348). Since filter efficiency increases with increasing particle size, the smaller, lower  $Cr^{6+}$ -containing particles in overspray are more likely to escape filtration than larger particles that contain more  $Cr^{6+}$ . With the similarity in the bias of the three primers studied, it is likely that the emission of  $Cr^{6+}$ , and possibly other inorganic solids, is overestimated.

# Possible Sources of Cr<sup>6+</sup> Bias

Although the exact mechanism explaining the Cr<sup>6+</sup> bias is not known, it is likely that the atomization process itself is responsible for the heterogeneous distribution of Cr<sup>6+</sup> in the overspray. One of the methods of secondary atomization described earlier may have caused the shearing of small, non-Cr<sup>6+</sup>-containing droplets off of larger droplets that contained solid SrCrO<sub>4</sub> particles in the core of the droplet. Also, it is possible that some of the smaller particles were formed during initial atomization were too small to contain the larger, solid particles of SrCrO<sub>4</sub>. The relatively smaller Cr<sup>6+</sup> concentration detected in these small particles would most likely come from dissolved Cr<sup>6+</sup> in the paint mixture, which is relatively small compared to the Cr<sup>6+</sup> present in solid form (i.e., SrCrO<sub>4</sub> powder).

## APPENDIX A-1: Calculation for Cr<sup>6+</sup> Content in Solvent EP

This appendix documents the calculations used to determine the percent (by mass) of  $Cr^{6+}$  in the dry paint being tested.

First, relevant data from the Product Data Sheets and MSDS are given.

Paint Type: Solvent-Based Epoxy-Polyamide Primer

#### Parameters from Product Data Sheets and MSDS:

Base Component	Primer Component	Percent (by mass)	Percent (by mass)
Density	Density	Cr <sup>6+</sup> in Base	Solids in Mixed
(lbs/gal)	(lbs/gal)	Component	Primer Paint
11.21	7.76	25% (w/w)	72.72% (w/w)

Mix Ratio:

3 parts base component to 1 part catalyst component

#### Additional Information:

Atomic Weight of Cr<sup>6+</sup>: 52.0 g/g-mole Molecular Weight of SrCrO<sub>4</sub>: 203.6 g/g-mole

Next, the density of the mixed primer is calculated based on the volumetric mix ratios of the primer components and the densities of these components.

#### Density of Mixed Primer Paint:

$$\left(\frac{3 \text{ parts base}}{4 \text{ parts mix}}\right) x \frac{11.21 \text{ lb}}{\text{gal}} + \left(\frac{1 \text{ part catalyst}}{4 \text{ parts mix}}\right) x \frac{7.76 \text{ lb}}{\text{gal}} = 10.35 \frac{\text{lb}}{\text{gal}} \text{ paint}$$

Given the calculated primer density, the percent (by mass) of SrCrO<sub>4</sub> was determined. The numerator represents the mass of SrCrO<sub>4</sub> in one gallon of mixed primer (note: All SrCrO<sub>4</sub> is from the base component; the catalyst contains no chromium.). The denominator represents the mass of mixed primer (i.e., the density of the mixed primer).

Percent (by mass) SrCrO<sub>4</sub> in Mixed Primer Paint:

$$\frac{25\% \text{ SrCrO}_4 x \left(\frac{3 \text{ parts base}}{4 \text{ parts mix}}\right) x \frac{11.21 \text{ lb}}{\text{gal}}}{10.35 \text{ lb/gal paint}} = 20.3\% \text{ (w/w)SrCrO}_4$$

Next, the percent (by mass) of  $SrCrO_4$  in the mixed primer was converted to the percent (by mass) of  $Cr^{6+}$  in the mixed primer. This conversion was based on the ratio of the atomic weight of chromium over the molecular weight of  $SrCrO_4$ .

# Percent (by mass) Cr<sup>6+</sup> in Mixed Primer Paint:

$$20.3\% \, \text{SrCrO}_{4} \, x \frac{52.0 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{Cr}^{6+}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{SrCrO}_{4}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{g}_{\text{g - mol}}^{\text{g}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g - mol}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+} \, \text{in Mixed Primer}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g - mol}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g - mol}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g - mol}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+}}{203.6 \, \text{c}_{\text{g - mol}}^{\text{g - mol}} \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+}} = \frac{5.19\% \, (\text{w/w}) \, \text{Cr}^{6+}} = \frac{5.19\%$$

Lastly, the percent (by mass) of  $Cr^{6+}$  in the dry primer was determined based on the fraction of non-volatiles in the mixed paint. Multiplying the percent  $Cr^{6+}$  in the "wet" primer by this fraction yields the percent  $Cr^{6+}$  in the "dry" paint.

# Percent (by mass) Cr<sup>6+</sup> in Dry Primer Paint:

5.19% (w/w) 
$$Cr^{6+}$$
 in Mixed Primer  $x = \frac{.7272 \text{ lb dry paint}}{1 \text{ lb mixed paint}} = \frac{7.13\% \text{ (w/w) } Cr^{6+} \text{ in Dry Paint}}{...}$ 

This procedure was repeated for the Water EP and Polyurethane primers in Appendices A-2 and A-3.

## APPENDIX A-2: Calculations for Cr<sup>6+</sup> Content in Water EP

Paint Type: Water-Based Epoxy-Polyamide Primer

#### Parameters from Product Data Sheets and MSDS:

Base Component	Primer Component	Percent (by mass)	Percent (by mass)
Density	Density	Cr <sup>6+</sup> in Base	Solids in Mixed
(lbs/gal)	(lbs/gal)	Component	Primer Paint
10.80	9.34	30% (w/w)	34.08% (w/w)

Mix Ratio: 2 parts base component to 1 part catalyst component

with a 4.1 parts water reduction

#### Additional Information:

Atomic Weight of Cr<sup>6+</sup>: 52.0 g/g-mole Molecular Weight of SrCrO<sub>4</sub>: 203.6 g/g-mole Water Density: 8.34 lbs/gal

#### Density of Mixed Primer Paint:

$$\left(\frac{2 \text{ parts base}}{7.1 \text{ parts mix}}\right) x \frac{10.80 \text{ lb}}{\text{gal}} + \left(\frac{1 \text{ part catalyst}}{7.1 \text{ parts mix}}\right) x \frac{9.34 \text{ lb}}{\text{gal}} + \left(\frac{4.1 \text{ parts water}}{7.1 \text{ parts mix}}\right) x \frac{8.34 \text{ lb}}{\text{gal}} = 9.174 \frac{\text{lb}}{\text{gal}} \text{ paint}$$

#### Percent (by mass) SrCrO<sub>4</sub> in Mixed Primer Paint:

$$\frac{30\% \operatorname{SrCrO}_{4} x \left(\frac{2 \operatorname{parts base}}{7.1 \operatorname{parts mix}}\right) x \frac{10.80 \operatorname{lb}}{\operatorname{gal}}}{9.174 \operatorname{lb/gal paint}} = 9.9\% \text{ (w/w)SrCrO}_{4}$$

# Percent (by mass) Cr<sup>6+</sup> in Mixed Primer Paint:

9.9% SrCrO<sub>4</sub> 
$$x \frac{52.0 \frac{g}{g} - \text{mol Cr}^{6+}}{203.6 \frac{g}{g} - \text{mol SrCrO}_4} = \frac{2.54\% \text{ (w/w) Cr}^{6+} \text{ in Mixed Primer}}{203.6 \frac{g}{g} - \text{mol SrCrO}_4}$$

# Percent (by mass) Cr<sup>6+</sup> in Dry Primer Paint:

2.54% (w/w) 
$$Cr^{6+}$$
 in Mixed Primer  $x = \frac{.3408 \text{ lb dry paint}}{1 \text{ lb mixed paint}} = \frac{7.46\% \text{ (w/w) } Cr^{6+} \text{ in Dry Paint}}{1 \text{ lb mixed paint}}$ 

# APPENDIX A-3: Calculations for Cr<sup>6+</sup> Content in Polyurethane

Paint Type: Solvent-Based Elastomeric Polyurethane Primer

#### Parameters from Product Data Sheets and MSDS:

	Base Component	Primer Component	Percent (by mass)	Percent (by mass)
	Density	Density	Cr <sup>6+</sup> in Base	Solids in Mixed
	(lbs/gal)	(lbs/gal)	Component	Primer Paint
ı	11.63	7.96	20% (w/w)	70.84% (w/w)

Mix Ratio:

1 part base component to 1 part catalyst component

#### Additional Information:

Atomic Weight of Cr<sup>6+</sup>: 52.0 g/g-mole Molecular Weight of SrCrO<sub>4</sub>: 203.6 g/g-mole

#### Density of Mixed Primer Paint:

$$\left(\frac{1 \text{ parts base}}{2 \text{ parts mix}}\right) x \frac{11.63 \text{ lb}}{\text{gal}} + \left(\frac{1 \text{ part catalyst}}{2 \text{ parts mix}}\right) x \frac{7.96 \text{ lb}}{\text{gal}} = 9.795 \frac{\text{lb}}{\text{gal}} \text{ paint}$$

#### Percent (by mass) SrCrO<sub>4</sub> in Mixed Primer Paint:

$$\frac{20\% \text{ SrCrO}_4 x \left(\frac{1 \text{ parts base}}{2 \text{ parts mix}}\right) x \frac{11.63 \text{ lb}}{\text{gal}}}{9.795 \frac{\text{lb}}{\text{gal}} \text{ paint}} = 11.87\% \text{ (w/w)SrCrO}_4$$

# Percent (by mass) Cr<sup>6+</sup> in Mixed Primer Paint:

$$11.87\% \, SrCrO_4 \, x \frac{52.0 \, \frac{g}{g} - mol \, Cr^{6+}}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{6+} \, in \, Mixed \, Primer}{203.6 \, \frac{g}{g} - mol \, SrCrO_4} = \frac{3.03\% \, (w/w) \, Cr^{$$

# Percent (by mass) Cr<sup>6+</sup> in Dry Primer Paint:

3.03% (w/w) 
$$Cr^{6+}$$
 in Mixed Primer  $x = \frac{.7084 \text{ lb dry paint}}{1 \text{ lb mixed paint}} = \frac{4.28\% \text{ (w/w) } Cr^{6+} \text{ in Dry Paint}}{...}$ 

# APPENDIX B-1: Deft® Product Data Sheets for Solvent-Based Epoxy-Polyamide Primer Paint (MIL-P-23377G, Type I, Class C)





***********		75.00		
	Mix or catalyst ratio  Reduction	st Component( se Component( talyst component( pecification(	02-Y-40 CATA.) L-12441) L-12393) MIL-P-23377G Type 1 Class C) Color: Strontlum Chromate Yello 3:1 by volume)	w )
	BASE CHARAC	TERISTICS	CATALYST CHARACTERISTICS	
	Wt./Gal. % solids by weight % solids by volu VOC pounds/galle.i VOC grams per liter—(	(73.10%) (55.52%) (3.01)	Wt./Gal	1%) 4%)
	CHARACTERISTICS AS	3 APPLIED (NO REDU	CTTON	
	Wt./Gal	( 72.72% ) ( 58.55% ) -( 2.82 )	Wt./Gal.of Solids [12.85 lbs Sq./Ft. coverage @ 1 mil dry [937 Sq./Ft. @ 1 mil dry [3.68 gram]	Ft. )
	QUALIFIED TEST RES	ULTS	W. A.	
	(1) Pigment Composition (2) Pigment Weight Perce (3) Fineness of Grind (AS (4) Volatile Organic Comp (5) Storage Stability (3.5.) (6) Accelerated Storage Si (7) Viscosity catalyzed an (8) Dry-Time (3.4.3)	(3.4.1.1)Strontium ( Siliceous E other addit nt of Base Component ( STM Method D-1210) = counds (VOC) content ( 3) 1 year at temperatur tability (3.5.4) 14 days d unreduced (3.6.3) = counds (VOC) = No spec	per liter maximum338 ge of 35' to 115;f	;./L ec.
	T	lack Free = 5 hours ma	C	<b>3</b>
	Ľ	Dry Hard = 8 hours ma:	C8 hours	5

(9) Condition in Container (3.5.1) (Base Component ) Will stir into a smooth,
homogeneous condition.
(Catalyst Component ) Will be clear & clear.
(10) Adhesion (3.7.4) No loss of adhesion after 24 hours of water immersion
at temperature of 65' to 85'FNo Adhesion Loss
(11) Induction Time (4.5.1) 30 minutes maximum30 min.
(12) Application of primer coating (4.5.1 ) Apply film at 0.6 to 0.9 mils0.9 mils
(13) Water Resistance (3.8.1) Topcoated primer immersed for 4 days
at 1907 and 1908 at 1908
at 120'F + 5'F = No DefectsNo defects
(St. lose of color)
(14) Flexibility (3.7.5) Impact elongation = 10%
(15) Lifting 3.7.3 ) No lifting of MIL-C-85285B Polyurethane
Topcoat after:
Topcoat @ 2 hours (no spec.)————No Lifting
Topcoat @ 3 hours (no spec.)No Lifting
Topcoat Ø 5 hours—No Lifting
(16) Strippability 3.7.6) Within 60 minutes with a stripper conforming
to MIL-R-81294, Type 1 = 90% minimum
(17) Salt Spray Resistance (3.8.2.1.1) 2000 hours with a 5% solution
No blistering, lifting or corrosionNo Defect
(18) Topcoating (3.5.11 ) To be topcoated with a polyurethane conforming
to MIL-C-85285B. Color # 17925No lifting
(19) Filliform (3.8.2.2 ) After 1000 hours at 104F and a relative
humidity of 80 + 5% = No Defects
(20) Pot-Life (3.6.4) After 4 hours at room temperature 65' to 85'F
catalyzed and unreduced =70 seconds maximum30 sec.
(21) Fluid Resistance (3.8.4) No softening, blistering, loss of adhesion
or film defects after 24 hours at 250°F
MIL-L-23699-*****No Defects
MIL-H-83282No Defects

# EPOXY POLYAMIDE PRIMER DESCRIPTION AND APPLICATION INFORMATION DESCRIPTION:

Chemically cured two component epoxy-polyamide primer suitable for application on aircraft and aerospace equipment. Component 1 contains the pigment and epoxy resin. Component 11 is the clear non-pigmented aliphatic polyamine-epoxy portion which acts as the hardener or curing agent for Component 1.

#### AIR POLLUTION REGULATIONS:

This product is formulated for use where the air pollution regulations call out for a maximum VOC of 340 grams per liter.

#### SPECIAL FEATURES:

This epoxy-polyamide primer is a solvent borne, corrosion inhibiting and chemical and solvent resistant primer

#### APPLICATION:

This primer will spray satisfactorily in all respects and shall show no running, sagging or streaking. The dry film shall show no dusting, mottling or color separation and shall present a smooth finish free from seeds. The standard film thickness shall be 0.6 to 0.9 mils dry.

# APPENDIX B-2: Deft® MSDS for Solvent-Based Epoxy-Polyamide Primer Paint (MIL-P-23377G, Type I, Class C)

```
NATERIAL SAFFTY DATA SHEET Printed: 07/19/01
For Coatings, Resins and Related Materials
Revised: 07/09/01
      Page: 1
    IRVINE CA
  Product Class: TYPE T. CLASS C | Health - 4 | Hazard Satings: Health - 4 | Frade Name : MIL-PEP-23177G (MIL-P-23177G) ! 0 ---> 4 | Reactivity - 1 | Frade Name : MIR | MINE | Health - 4 | 
      SECTION II - HAZARDOUS INGREDIENTS
  | The first constant 
                                                                                                                                                                                                                                                                                                                                                ..... Exposure Limite ....
                                                                                                                                                                                                           K-METHYL PYRROL I DESIG
                                    THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST
                                   ALSO ANY UNLISTED INCREDIENTS.
  N.E. - Not Established
SECTION III - PHYSICAL DATA

Boiling Range: 213 - 196 Deg. F Vapor Density: Heavier than Air.
Evap. Rate: 1.66 x n-Butyl Acetate Liquid Density: Heavier than Air.
Volatiles vol % 44.8 NgtR 27.6 Wgt per gailon: 11.23 Founds.
Appeatance: YELLOW LIQUID WITH SOLVENT ODOR
V.O.C.: 361 G/L
V.O.C.: 361 G/L
SOLVENITION TERPERATURE: No information found
DECOMPOSITION TERPERATURE: No information found
DECOMPOSITION TERPERATURE: No information found
    CORROGION RATE: No information found
VISCOSITY Thin liquid to heavy viscous material
  -SPECIAL FIREFIDETING PROCEDERS:

PULL fire fighting equipment with self-contained breathing apparatus and full protective clothing should be worn by fire fighters. Nater may be used to cool closed containers to prevent pressure build-up, suto ignition or explosion.

-UNISUAL FIRE & EXPLOSION HAZARDS:

News containers tightly closed. Include from heat, sparks, electrices equipment and open flame. Closed containers may explode when exposed to extreme heat, Application to hot surfaces requires special precautions. Buring emergency conditions oversexpours to decomposition products may cause a health hazard. Symptoms may not be immediately apparent.

SECTION V - MEALIN HAZARD DATA
-PERMISSIBLE EXPOSURE LEVEL:
  - PERHISSIBLE EXPÓSURE LEVEL:
SER SECTION II, HAZARDOUS INGREDIENTS
  -EFFECTS OF OVEREXPOSURE:
                                 TTS OF OVEREXPOSURE:
INHALATION: Irritation of the compiratory tract 4 scate nervous system depression characterized by the following propressive steps! headache, dizziness, staggering gait, confusion. unconsciousness or come.

SRIN AMD EYE CONTACT: SRIN: Contact with the skin can cause irritation. Symptoms may be swelling, redness, and rash.
```

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MATERIAL SAFETY DATA SHEET Printed: 07/19/01
For Coatings, Resins and Related Materials
[SRevised: 07/09/01]
   Page: 1
     SECTION I - PROJECT INDESTIFICATION
   Manufacturer: DEPT, INC. (CAGE CODE 33461) Information Phone: (949) 474-0400
17451 VON KARHAN AVENUE Regency Phone: (800) 424-9300
CHEMTREC Phone: 800-424-9300
                              TRUTME
  Product Class: TYPE I, CLASS C | Hazard Ratings: Bealth - 3
Trade Mane : MIL-PF-23377G (MIL-P-23377G) | 0 ---> 4 Reactivity - 1
Product Code : 02T040CAT | C.A.S. Number: MONE |
                            SECTION II - HAZARDOUS INGREDIENTS
                                                                                     Meight ACGIH CSHA
t TLV STEL PEL STEL
  Ingredients
                                                                        CAS #
                                                                        ALIPHATIC AMINE
                                                                                                                                                                                                    ы.в.
  ALTEGATIC AKINE
                                                                                                                                                                                                   M.E.
  ALIPHATIC ANIME
                                                                                                                                                                                                   N.E.
                                                                       ALIPHATIC AMINE
                                                                                                                                                                                                   N.E.
  Sec-MITTYL ALCOHOL
                                                                                                                                                                                                   N.E. 12.5 @ 68F
  AROMATIC HYDROCARBOM
                                                                                                                                                                                             N.E. 3 0 68F
150 ppm 5.1 0 68F
N.E.
N.E.
  XYLENE
1,2,4 TRIMETHYLBENZENE
  CTROPPER
  COMENS
1.3.5 TRIMETHYLDENZENE
DIETHYLDENZENE
                                                                                                                                                                                                    N.E.
                                                                        ETHYL BENZEME
                                                                        100-41-4 < 0.1 100 ppm 125 ppm 100 ptm IARC has determined that ethylbenzene is possibly
                                                                                                                                                                                DDM
                                                                                                                                                                                              125 ppm 7.1 8 68P
                                                                                                                                               250 ppm
M.B.
M.R.
                                                                                                                                                                       200 ppm.
N.E.
N.E.
  ANTINO STLANE ESTER
                                                                                                                                                                                                250ppm
M.E.
M.E.
 EPOXY RESIN HARDENER
EPOXY RESIN HARDENER
                                                                                                                                                                                                                   0 9 70F
            THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST. ALSO ANY UNLISTED INGREDIENTS.
SECTION III - PHYSICAL DATA

boiling Range: 211 - 401 Deg. F Vapor Density: Heavier than Air.

byap. Rate: 0.63 x n-Butyl Acetate Liquid Density: Lighter than Water.

Volatiles wol % 34.8 Wgf% 29.7 Wgf per gallon: 7.90 Pounds.

Appearance: AMBER LIQUID WITH SOLVENT ODOR

V.O.C.: 281

SCLUBILITY IN WATER: Insoluble PH: Not applicable

APPOINTION THEFERATURE: No information found

CORROSITION TATE: No information found

VISCOSITY: Thin liquid to heavy viscous material
 N.E. w Not Established
                                   SECTION IV - FIRE AND EXPLOSION HAZARD DATA
 Flammability Class: IB Flash Point: 57 F TCC LEL: 0.90% UEL: 9.80%
-EXTINGUISHING MEDIA:
POAM, ALCOHOL POAM, CO2, DRY CHEMICAL, WATER FOG
-SPECIAL PIERFIGHTING PROCEDURES:
-special First and Procedures:
Pull fire fighting equipment with self-contained breathing apparatus and full protective clothing should be worn by fire fighters. Water may be used to cool closed containers to prevent pressure build-up, ento ignition or explosion.

-unusual Fire a Explosion Hazards:

Keep containers tightly closed. Isolate from heat, sparks, electrical equipment and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions. During emergency conditions overexposure to decomposition prochats may cause a health hazard. Symptoms may not be immediately apparent.
                                              SECTION V - HEALTH HAZARD DATA
-PERMISSIBLE EXPOSURE LEVEL:
SEE SECTION II, BAZARDOUS INGREDIENTS.
-EPPECTS OF OVEREXPOSURE:
           INBALATION: Irritation of the respiratory tract & soute nervous
system depression characterized by the following progressive
steps: headache, dirriness, staggering gait, confusion,
unconsciousness or come.
```

# APPENDIX C-1: Deft® Product Data Sheets for Water-Based Epoxy-Polyamide Prime r Paint (MIL-PRF-85582C, Type I, Class C)



# PRODUCT INFORMATION DATA SHEET

Product Code Base Component- Product Code Catalyst Component- Batch Number of Base Component- Batch Number of Catalyst component Product to meet Specification Product to meet Color Mix or catalyst ratio Reductor	(44-GN-72 Cata.) (L-13265) at(L-13266) (MIL-PRF-85582C Type I, Class C2) (Color: PROPOSED COLOR) (2:1 by volume) (4 Parts by volume approximate)
BASE CHARACTERISTICS	CATALYST CHARACTERISTICS
Wt/Gal(10.80) % solids by weight(74.25%) % solids by volume(58.77%) VOC pounds/gallon(2.80) VOC grams per liter(333)	Wt./Gal(9.34) % solids by weight(69.28%) % solids by volume(67.16%) VOC pounds/gallon(2.87) VOC grams per liter(344)
CHARACTERISTICS AS CATALYZED	NO REDUCTION
Wt/Gal	Wt/Gal.of Solids(12.08 lbs) Sq./Ft. coverage @ 1 mil dry(987 Sq./Ft.) Grams per sq./Ft. @ 1 mil dry(3.46 grams)
Class C2 * Strontium Chromate  Physical Properties: (3.4.1) Color  Type I The color of the admixed type I primer co	gment Passes Passes ating shall be the natural color of the Passes
Fineness Of Grind: (Para. 3.4.3) The fineness of	erind of the admixed primer coating
Condition In Container: (Para 3.4.5) Componer	nt A and Component B will stir into a
Pot-Life: (Para.3.4.4) Viscosity at the start (#4 After 4 hours at room temperature of 73°F±5°F	Ford Cup )
Storage Stability: (Para 3.4.6) This primer will: the date of manufacturing when in an unopened of (35°F to 115°F)	entainer at a temperature of
Accelerated Storage Stability: (Para.3.4.7) = 7 d	Passes ays at 120°F ± 1°F Passes
Pa	gc I of 4

(Issued: 3 / 99 )

9.	Freeze Thaw Stability: (Para.3.4.8) This primer shall pass 5 cycles at 16 hours at 15°F ± 5°F followed by 8 hours at 77°F per cycle
10.	Dry Time: (Para 3.5.2) Under an air flow of 88 feet per minute the primer shall dry
	as follows:
	(a) Tack Free (60 minutes maximum)
	(b) Dry Hard (6 hours maximum)
13.	Lifting: (Para 3.5.3) There shall be no lifting of the MIL-C-85285B Polyurethane Topcoat
	after the following:
	(a) Topcost @ 2 hours No Lifting
	(b) Topcoat @ 4 hours
	(c) Topcoal @ 18 hours No Litting
14.	Adhesion = Wet Tape: (Para.3.5.4) No loss of adhesion after 24 hours of immersion
	in distilled water at room temperature ( 77°F)
15.	Flexibility: (3.5.5) The primer shall pass an Impact elongation of 10%
16.	Strippability: (Para 3.5.6) 90% of the primer will be stripped with in 15 minutes
	with remover conforming to MIL-R-91294 Class I at room temperature (77°F)
17.	Infrared Reflection ( Para 3.5.7) Type II Primer Only :
18.	Water Resistance: (Para 3. 6.1) The primer coating with and without a topcoat shall
	with-stand immersion in distilled water maintained at 49°±3°C for four days without
	exhibiting any evidence of softening, wrinkling, blistering or other deficiency
TO	Salt Spray: (Para 3.6.2.1) With and with-out Topocat of polyurethane conforming
* **	to MIL-C-85285B shall show no blistering after 2000 hours at 5%
	(a) Aluminum
	(b) Aluminum / Graphite Epoxy
<b>ማ</b> ለዩ	Filiform: (3.6.2.2) Exhibit no filiform corrosion beyond ¼ inch from scribe.
AV.	Majority of filaments less than 1/8 inch
44.4	Fluid Resistance: (Para.3.6.3) This primer shall withstand 24 hours immersion of
ÆL.	the following:
	(a) MIL-L-23699 Lubricating Oil @ 250°F ± 5°F Passes
	(b) MIL-H-83282 Hydraulic Fluid @ 150°F ± 5°F
w64424200000	180000313131885777800000000000000000000000000000000

# EPOXY POLYAMIDE, WATER REDUCIBLE PRIMER DESCRIPTION AND APPLICATION INFORMATION

<u>DESSCRIPTION</u>: Chemical cured two component epoxy polyamide water reducible primer for application on ferrous and non-ferrous metals. Component A contains the pigment and polyamide resin. Component B is the clear non-pigmented epoxy portion which acts as the hardener or curing agent for Component A.

AIR POLLUTION REGULATIONS: This product is formulated for use where the air pollution regulations call out for a maximum volatile organic compound (VOC) of 340 grams per liter.

SPECIAL FEATURES: This epoxy polyamide primer is a water reducible, corrosion inhibiting chemical and solvent resistant primer.

APPLICATION: This primer will spray satisfactorily in all respects and shall show no running, sagging or streaking. The dry film shall show no dusting, mortling or color separation and shall present a smooth finish free from seeds. The standard film thickness shall be 0.6 to 6.9 mils dry.

MIXING INSTRUCTIONS:

Component A 2-Volumes Component B L-Volume Water 4.1-Volumes

1.0

Add all of the <u>Catalyst Component</u> to the short filled can containing the <u>Base Component</u>. Then use one of the following methods for mixing.

Page 2 of 4

(Issued: 3 / 99)

# APPENDIX C-2: Deft® MSDS for Water-Based Epoxy-Polyamide Primer Paint (MIL-PRF-85582C, Type I, Class C)

For Coatings.		olated Materi	als	ed : 07/26/ ed : 06/16/				
La L	35 45 45 46 46 16 46 46 46 46 4		AND INCOME OF REPORT SHEET	or day day table and terrified that table day days us	01 SEC 400 TOU. Sec.			
Assatscturer 17451 Von KARSW	33461)	Information	Phone	(949) 474-	0400			
17451 VON KARMAN	AVENUE CA	Emergency CHEMTREC	Phone:	(800) 424- : 800-424-93	9300 00			
22514				er err werden ver olle dat aus uur aus aus aus	anackankan kantar			
Product Class: TYPE I,CL C2,FOL Trade Name : HIL-FRF-85582C, Product Code : 44GM072 C.A.S. Number: MONE		Hazard Rat Home -> ex	ings: dreme d	Health Fire Reactivity	- 3 - 3 - 1			
SECTION	II - HATARIXH	OS TREREDIEM	19					
				6	henrom cera	Limits		
Ingredients	CAS #	Weig	int T	ACSI TLV	H STEL	PEL	OSHA STEL	
sec-BUTYL ALCOHOL C8610 ARCHATIC HYDROCARDON	78-92-2 64742-95-	-6 <	5. J 1.	N.E.	И.В. И.В.	100 ppm H.E.	N.E. M.E.	12.5 9 6: 3 9 6:
STRONTIUM CHROMATE	Mara	itacturer rec	ORDER DE L'ANDRE DE L'	a PEL of 1	.00 ppm.	*		
STEEDST TONE STRONGSTO	The	ACCIDE TWA TO	e seroe	cium Chroma	te (CAS	7789-06-2)	as Cr	
		0.0005 mg/m3.						
THE ABOVE LISTED PRODUCTS ALSO AMY UNLISTED INGREDI		SCA INVENTORY	LIST.					
W.E. = Not Established		,						
	ON III - PHY:	SICAL DATA	. 3					
		CONTRACTOR AND		and the same of th	165° 0011 0015-001			
Noiling Range: 211 - 335 Deg Evap. Rate: 0.65 x n-Butyl Folatiles vol t 43.1 Wgtt	. r	por Density Lquid Density pt per gallon	Hesvi	er taan Mir er than Wat 80 Pounds.	**************************************			
Appearance: GREEN LIQUID WITH S	OSWENT ODOR :	Spec. Gravity	h L	29652				
V.O.C.: 334		Not applicabl	_				4	
SCHABILITY IN WATER: Insoluble ANTOIGNITICH TEMPERATURE: Bo in DECOMPOSITION TEMPERATURE: No i CORNOSION BATT: No information	formation four nformation for	nd .	æ					
VISCOSITY: This liquid to heavy	viscous mater	riml						
SECTION IV	- PIRE AMD EXE	PLOSTOM HAZAR	D DATA					
Flammability Class: IB Flas -EFTIMGUISHING MEDIA:	k Paint:72 P 7	PCC LEL: 1	.cox us	L: 9.80%				
-EFTINENISHING MEDIA: FORM: ALCOHOL FORM, CO2.: -SPECIAL PIREFIGHTING PROCEDURE:	DRY CHEMICAL, S:	WATER FOG	1.86	**	*			
Full fire fighting equipm apparatus and full protec	ent with self-	-contained be	esthing	!				
fighters. Water may be us	ed to cool clo	sed containe	rs to p	tevent				
pressure build-up, auto is	gnition or exp DS:	olosion.	***					
Keep containers tightly c electrical equipment and	losed. Isolate	from heat,	sparks,					
explode when exposed to ex	ttreme beat. A	emplication t	o bot					
surfaces requires special conditions overexposure to	o decessossicio	en percebacita m	aiv canas					
health hezard. Symptoms m	my not be imme	diately appa	rent.					
	V - HEALTE	HAZARD DATA						
-PERMISSIBLE EXPOSURE LEVEL: SEE SECTION II, HAXARDOUS								
-EFFECTS OF OVEREXIOSINE; INHALATION: Irritation of system depression characte	the respirate	wy tract & a following pr	cute ne ocressi	rvous ve	3			
steps: beadache, dizzines: unconscionsness or coma.	s, staggering	gait, confus:	ion,					
discomscholisasis of coler.		+ +						
SKIN AND EYE CONTACT: SKIN irritation. Symptoms may i EYES: Liquid, areosols, or tearing, rechess, and swe- sensation.	oe swelling, r : vapors are i	edness, and : rritating and	rash. d mav c					
SKIN AND EYE CONTACT: SKI irritation. Symptoms may I EYES: Liquid, areosols, on tearing, reduces, and swe	oe swelling, r r vapors are i lling accompan i or repeated	edness, and caritating am- ded by a stin	rash. d may c eging cause	ā 12 Sé				

MATERIAL SAFETY DATA SHEET Printed: 07/26/00 Page: 1 For Coatings, Resins and Related Materials Revised : 06/16/98 SECTION I - PRODUCT INSERTIFICATION Manufacturer: DEPT, INC. (CAGE CODE 33461) 17451 VON KARMAN AVENUE Information Phone: (949) 474-9400 Emergency Phone: (800) 424-9300 CHEMINE: Phone: 800-424-9300 IRVINE 92614 SECTION II - HAZARDOUS INGREDIENTS Weight ACGIH DEHY OSHY LV STEL ACGIH TLV CAS # STEL Ingredients 79-24-3 30. 100 ppm N.E. 100 ppm N.E. 16 0 68# THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST. ALSO ANY UNLISTED INSPEDIENTS. N.E. - Not Established SECTION III - PHYSICAL DATA

Vector Density: Vapor Density: Heavier than Air. Liquid Density: Heavier than Water. Wgt per gallon: 9.38 Pounds. Spec. Gravity: 1.12605 Boiling Range: 237 - 300 Deg. F Bwap, Rate: 1.27 x n-Butyl Acetate Volatiles vol % 32.2 Wgt% 30.1 Appearance: AMBER LIQUID WITH SOLVENT ODOR APPEARANCE INSURE INTO WITH SOURCE THE NOT APPLICABLE
V.O.C.: 145 G/L
SOUBLITY IN WATER: Insoluble PH: Not applicable
AUTOCOMPTION TEMPERATURE: No information found
CHEROSION RATE: No information tound
VISCOSITY: Thin liquid to heavy viscous material SECTION IV - FIRE AND EXPLOSION HAZARD DAYA Pleamability Class: IC Plash Point:87 F TCC LEL: 3.40% UEL: (
-ENTINGUISHING MEDIA:
-ENTINGUISHING MEDIA:
-ENTINGUISHING MEDIA:
-ENTINGUISHING MEDIA:
-ENTINGUISHING MEDIA:
-ENTINGUISHING MEDIA:
-ENTINGUISHING FROCEDURES:
-ENTINGUISHING FROCEDURES:
-ENTINGUISHING FROCEDURES:
-ENTINGUISHING FROM FIRE A EXPLOSION HAZARDS:
-ENTINGUISHING FROM HAZARDS:
-ENTINGUISHING 0.00% The a satisfactor assess:

Esep containers tightly closed. Isolate from heat, sparks, electrical equipment and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions. During emergency conditions everexposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent. SECTION V - HEALTH HAZARD DATA -PERMISSIBLE EXPOSURE LEVEL: SUB SECTION II, HAZARDOOS INGREDIENTS. -EFFECTS OF OVEREXPOSURE: THE OF CONTRACTORS IT TILES OF the respiratory tract & acute nervous system depression characterized by the following progressive steps: headache, dizziness, staggering gait, confusion, unconsciousmens or come. SEIN AND EYE CONTACT: SKIN: Contact with the skin can cause irritation. Symptoms may be swelling, redness, and rash. EYES: Liquid, areosols, or vapors are irritating and may cause tearing, redness, and swelling accompanied by a stinging sensation. SKIN ABSORPTION: Prolonged or repeated contact can cause moderate irritation, drying, and defatting of the skin which can cause the skin to crack. INGESTION: Acute: Can result in irritation and possible corrosive action in the mouth, stomach tissue and digestive tract. Vomiting may cause aspiration of the solvent, resulting in chemical pneumonitis. HEALTH HAZARDS (ACUTE AND CHROWIC)
ACUTS: Vapors are irritating to eyes, nose, and throat.
Inhalation may cause beadaches, difficult breathing and loss of

## APPENDIX D-1: Deft® Product Data Sheets for Solvent-Based Elastomeric, Polyurethane Primer Paint (TT-P-2760A, Type I, Class C)



### PRODUCT INFORMATION DATA SHEET

Product Code Base Component (09-Y-2)
Product Code Catalyst Component
Batch Number of Base Component(L-12370)
Batch Number of Catalyst Component(L-10711)
Product to meet MIL Specification(TT-P-2760A Type I Class C)
Product to meet Color Number(Tinted To Improve Hiding As Per Specification)
Mix or Catalyst Rano(1:1 By Volume)
Reduction (As VOC Will Allow)
Reducer(MIL-T-81772B Type I Polyurethane Reducer)

#### BASE CHARACTERISTICS

#### CATALYST CHARACTERISTICS

Wt/Gal(11.63) % solids by weight(81.65%) % solids by volume(72.25%) VOC remodeles llon (2.13)	Wt/Gal(7.96) % solids by weight(55.06%) % solids by volume(47.02%) VOC pownds/mallon(2.54)
VOC pounds/gallon (2.13) VOC grams per liter (255)	VOC pounds/gallon(3.54)
A O C Brown her mer "" ( CC7 )	VOC grams per liter(424)

#### CHARACTERISTICS AS APPLIED (NO REDUCTION)

Wt./Gal	Wt/Gal. of solids
VOC grams per liter(2.83)	

#### QUALIFIED TEST RESULTS

- Scope: (Para.1.1) This is a low Volatile Organic Compound (VOC), solvent borne, elastomeric, polyurethane primer coating. This primer coating is formulated primarily for spray application. It is compatible with polyurethane topocats and is intended for use on aircraft and other equipment subject to structural flexing at low temperatures.
- Classification: (Para.1.2) The coating shall meet the following:
  - Type I: Standard Pigments
  - Class I: Strontium Chromate based corrosion inhibitors
- Volatile Organic Compound (VOC) Content: The maximum VOC content of this primer coating at application shall be 340 grams per liter (2.80 lbs. per gallon). The resistivity of the solvents shall be suitable for electrostatic application.
- Condition In Container: (3.5.1) The coating components shall be capable of being easily mixed by hand, with a paddle, to a smooth, homogeneous, pourable condition and free from gelation.
- Storage Stability: (Para 3.5.2) The previously unopened packaged material shall be capable of meeting all
  requirements specified for a period of one year, when stored in an area where the daily temperature of the
  ambient air is with-in the range of (1.7°C to 46°C (35°F to 115°F).

Page 1 of 4

6. Color: (Para.3.5.4) The color of the Type I primer coating shall be the natural color of the corrosion inhibiting pigment used with the exception that tiating to a darker shade is permitted to improve hiding Fineness Of Grind; (Para 3.5.8) The fineness of grind, on the Hegman Scale shall be a minimum. of 5 ......5 8. Viscosity: (Para.3.6.4) The viscosity of the admixed costing after thinning Shall be in the range 9. Pot Life: (Para 3.6.5) After 2 hours in a closed container, the viscosity of the admixed coating shall not exceed 60 seconds through a No. 4 Ford Cup. The coating shall not get with-in 4 hours after mixing. Start 21.78 seconds #4 Ford Cup After 4 hours 22.02 seconds, after 8 hours no gel. 10. Drying Time: (Para 3.7.1.) The coating shall be spray applied to a dry film thickness of (1 1/4 to 2 mils) Cantion shall be taken when reducing the coating not to exceed the maximum allowable VOC content. The applied coating shall be allowed to dry at ( 70°F ± 10°F ) Tack Free (4-hours) 4-hours 11. Lifting: (Para 3.7.3) When separately applied to this primer coating that has air dried for 1,4 and 18 hours, the polymethane topcoat shall exhibit no lifting or other film irregularity. 12. Adhesion: (Para 3...7.4) The primer shall not peel away from the substrate after immersion in water for 24 hours. Passes 13. Ambient Flexibility: (Para.3.7.5.1) The primer coating shall exhibit a minimum impact elongation of 60%. Passes 14. Low Temperature Flexibility: (Para.3.7.5.2) The primer coating shall exhibit no cracking when bent over a 1/8 inch mandrel at a temperature of -60°F Passes 15. Water Resistance: (Para.3.8.1) The primer with the polyurethane topocat shall with-stand immersion for 4 days in distilled water at 120°F with-out exhibiting any softening, wrinkling blistering, loss of adhesion or other deficiency. Passes 16. Fluid Resistance: (Para 3.8.3) The primer shall exhibit no softening, blistering, loss of adhesion or other defects after immersion for 24 hours in the following; MIL-L-23699 Lubricating Oil (@ 250°F). Passes MIL-H-83282 Hydranlic Fluid ( @ 150°F ) Passes 17. Salt Spray: (Para 3.8.5.1) The primer coating shall exhibit no blistering, lifting of the 

#### POLYURETHANE DESCRIPTION AND APPLICATION INFORMATION

<u>DESCRIPTION</u>: Chemically cured two component polymerhane elastomeric primer suitable for application on aircraft and aerospace equipment. Component A contains the pigment and the oil-free polyester resin. Component B is the clear non-pigmented aliphatic isocyanate prepolymer portion which acts as the hardener or curing agent for Component A.

PIGMENTS: Shall have exterior durability and be lead free.

AIR POLLUTION REGULATIONS: This product is suitable for use where the air pollution regulations call out for a maximum VOC of 340 grams per liter or les

<u>SURFACE PREPARATION</u>: This product is designed for use over deoxidized aluminum, chromic acid anodized aluminum, sulfuric acid anodized aluminum, titanium, magnesium, steel, fiberglass, and Alodine 1000, 1200 and 1500 equivalent pre treatments.

#### APPENDIX D-2: Deft® MSDS

# Solvent-Based Elastomeric Polyurethane Primer Paint (TT-P-2760A, Type I, Class C)

```
HATERIAL SAFETY DATA SHEET Printed: 07/19/01
For Coatings, Resins and Related Materials
(RESTREE: 06/30/99)
  Page: 1
                                                                 SECTION I - PRODUCT INDESTIFICATION
 Hammfacturer: DEPT, INC. 3 (CAGE CODE 13461)
17451 VON KARHAN AVESUE
                                                                                                                                            Information Phone: (949) 474-0400
Emergency Phone: (800) 424-9300
CHEMITEC Phone: 800-424-9300
                                            ERVENE
                                            92614
 Fraction of the following control of the follo
                                                                   SECTION II - HAZARDOUS INGREDIENTS
                                                                                                             Ingredients
 n-BUTYL ACETATE
   RENYL 3-RTHORYPROPIONATE
 DISPERSION AID
  KYLEME
   BEHYL BIOMZENIZ
 ISOBUTYL ALCOHOL
ANTI-FLOAT AGENT
STRONTION CHRONATE
 METRYL ETHYL KETOWE
 2-4 PROFESSION TORRE
 DIBUTTLEIN DILAURATE
                  THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST.
 N.E. - Not Established
                                                                            Boiling Range: 175 - 401 Deg. F
Evap. Rate: 0.66 x n-Butyl Acetate
Volatiles vol % 28.6 Wgt% 19.0
Spec. Gravity:

Appearance: BROWN LIQUID WITH SOLVENT OFFICE

V.O.C.: 262 G/L

SOLUBILITY IN WATER: Insoluble PH: Not applicable
AUTOCOMPOSITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
 CORROSION RATE: No information found
VISCOSITY: Thin liquid to heavy viscous material
                                                     SECTION IV - FIRE AND EXPLOSION HAZARD DATA
                                                                       Plash Point:23 F TCC LEL: 1.00% UEL: 11.40%
Placeability Class: IB
                                                                        SECTION V - HEALTH HAZARD DATA
 -PERMISSIBLE EXPOSIBLE LEVEL:
 -PERMISSINGS EXPOSENCE LEVEL:
SEE SECTION 11, HAZARDOUS INGREDIENTS.
-EFFECTS OF OVEREXPOSUME:
INSULATION: Irritation of the respiratory tract & acute nervous system depression characterized by the following progressive steps: headache, dizzinems, staggering geit, confusion, unconsciousness or comma.
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MATERIAL SAFETY DATA SHEET Printed: 07/19/01
For Coatings, Resins and Related Materials
@Revised: 06/30/99
  Pace: 1
 SECTION I - PRODUCT INDESTITUTION

Manufacturer: DEPT, INC. (CAGE CODE 33461) Information Phone: (949) 474-0400
17451 VON KARMAN AVENUE Beergency Phone: (800) 424-9300
CHEMIREC Phone: 800-424-9300
                                                                                                                         | Hazard Ratiogs: Health - 4
| none -> extreme | Fire - 3
| 0 ---> 4 | Reactivity - 1
 Product Class: ALIPHATIC ISOCYANAYE
Trade Name : CAT.TT-F-2760A.TYF 1.CL C
Product Code : CEYOUZEATS
C.A.S. Musber: NOME
                                                                                                                                   Weight ACGIH STEL
                                                          SECTION II - HAZARDOUS INGRESOINDIS
                                                                                                                                                                                                                                              OSHA
PRI. STEL
                                                                                                                                                                                                                                                                                                non ERG
  Ingredients
                                                                                                CAS #
  POLYMERIC HEXAMETHYLENE DIISOCYAMAT 28182-81-2
                                                                                                S22-06-0

HERAMETHYLENE DIISOCYAMATE (HDI) CAS NO. S22-06-0, free monomer content averages 0.10% based on resin solids at the time of meanufacture. However, after 12 months storage, the free monomer content may rise to a maximum of 0.14%. The ACMIH has a TLV of 0.005 ppm TMA.

20. 50 ppm 75 ppm 75 ppm 75 ppm 75 ppm 75 ppm 200 ppm 200 ppm 200 ppm
                                                                                                                              700 ppms 1742.
20.
< 5.
                                                                                                                                                                      50 ppm
150 ppm
200 ppm
                                                                                                                                                                                                      75 ppm
200 ppm
300 ppm
                                                                                                 108-10-1
123-86-4
                                                                                                                                                                                                                                    50 ppm
150 ppm
                                                                                                                                                                                                                                                           75 ppm
200 ppm
  METHYL ISOSUTYL KETOME
  n-bupyl aceyate
Bethyl ethyl keksæ
                                                                                                                                                                                                                                    200 ppm
                                                                                                 78-93-3
                                                                                                                                                    20.
                                                                                                                                                                                                                                                                   300ggan
                THE ABOVE LISTED INGREDIENTS ARE ON THE TSCA INVENTORY LIST, ALSO ANY UNLISTED INGREDIENTS.
 N.E. . Not Established
 SECTION III - PHYSICAL DATA

Boiling Runge: 175 - 460 Deg. F Vapor Density: Heavier than Air.

Hwap. Rate: 2.92 x n-Butyl Acetate Liquid Density: Lighter than Water.

Volatilas vol t 51.5 Wgrt 43.5 Wgt per gallon: 7.98 Pounds.

Spec. Gravity: 0.95798
 Spec. Gravi V.O.C.: 420 G/L SOLUBBLITY IN WATER: Insoluble FH: Not applicable AUTOGRATITION TEMPERATURE: No information found DECOMPOSITION TEMPERATURE: No information found CORROSION BATE: No information found
  VISCOSIVY: Thin liquid to heavy viscous material
                                                SECTION IV - PIRE AND EXPLOSION HAZARD DATA
 Planmability Class: IB
                                                                  Flash Point:23 F TCC LEL: 1.20% UEL: 11.00%
PROMERSHING MEDIA:

POAM, ALCOHOL POAM, CO2, DRY CHEMICAL, WATER POG, WATER SFRAY

SPECIAL FIREFIGHTING PROCEDURES:

Pull fire fighting equipment with self-contained breathing apparatus and full protective clothing should be worn by fire fighters. Water may be used to cool closed containers to prevent pressure build-up, auto ignition or explosion. During a fire HOI vapors and other irritating vapors may be generated by combination or thermal decomposition.

-UMNIUAL FIRE & EXPLOSION HAZARDS:

Keep containers tightly closed. Isolate from heat, sparks, electrical equipment and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions. During smergency conditions overceposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent.

SECTION V - HEALTH HAZARD DATA
  -EXTINGUISHING MEDIA:
                                                              SECTION V - HEALTH HAZARD DATA
  -PERMISSIBLE EIPOSURE LEVEL:
SUB SECTION II, HAZARDOUS IMMREDIENTS.
-EFFECTS OF OVEREXPOSURE:
                The Of Overhands of the respiratory tract A acute nervous system depression characterized by the following progressive steps: headache, dizziness, staggering gait, confusion.
                steps: headache, distiness, staggering gair, confusion, unconsciousness or come.

SKIN AND ETE CONTACT: SKIN: Isocyanates react with skin protein and moisture and can cause irritation. Symptoms may be swelling, redness, and rash.

EYES: Liquid, areosols, or vepors are irritating and may cause tearing, redness, and swelling accompanied by a stinging
                 SKIN ABSORPTION: Prolonged or repeated contact can damse
moderate irritation, drying, and defatting of the skin which can
```

# APPENDIX E-1: Raw Data Table for Solvent-Based Epoxy-Polyamide Primer Paint (MIL-P-23377G, Type I, Class C)

Large Particle-Size Range Impactor (Mass Cr <sup>6+</sup> per Mass Dry Paint) x 100%								
Stage:	1	2	3	4	5	6	7	
	9.63%	4.42%	5.32%	7.69%	6.44%	3.94%	2.45%	
	7.99%	4.38%	4.94%	7.70%	6.34%	4.04%	ND	
	5.61%	4.01%	4.24%	7.08%	ND	3.90%	2.42%	
	ND	ND	ND	ND	6.70%	5.65%	3.20%	
	8.35%	ND	ND	8.55%	ND	7.65%	4.22%	
	ND	2.33%	5.96%	ND	ND		ND	
	5.48%	5.00%	5.44%	5.94%	5.54%	3.77%	2.30%	
	4.58%	6.54%	5.14%	6.28%	5.83%	4.42%	2.84%	
Mean %Cr:	6.94%	4.45%	5.17%	7.20%	6.17%	4.77%	2.90%	
n =	6	6	6	6	5	7	6	
std dev =	1.99%	1.37%	0.57%	0.98%	0.47%	1.42%	0.73%	

Small Particle-Size Range Impactor (Mass Cr <sup>6+</sup> per Mass Dry Paint) x 100%								
Stage:	1	2	3	4	5	6	7	
		6.33%	ND	2.79%	1.50%	0.83%	0.68%	
		5.56%	4.13%	2.66%	1.82%	1.27%	0.89%	
		7.21%	ND	1.20%	1.19%	0.84%	0.75%	
		4.92%	2.61%	1.77%	0.81%	0.51%	ND	
		8.71%	6.83%	3.66%	2.61%	1.44%	0.98%	
		8.71%	ND	2.46%	2.52%	1.69%	1.42%	
		9.30%	4.40%	2.67%	1.24%	1.25%	0.93%	
		5.97%	4.07%	2.67%	2.25%	1.64%	1.29%	
Mean %Cr:		7.09%	4.41%	2.48%	1.74%	1.18%	0.99%	
n =		8	5	8	8	8	7	
std dev =		1.65%	1.53%	0.73%	0.67%	0.42%	0.27%	

Note: ND denotes data was collected, but lost before analysis was complete

# APPENDIX E-2: Raw Data Table for Water-Based Epoxy-Polyamide Primer Paint (MIL-PRF-85582C, Type I, Class C)

Large Particle-Size Range Impactor							
	(Mass	Cr <sup>6+</sup> per	Mass D	ry Paint)	x 100%	)	
Stage:	1	2	3	4	5	6	7
	ND	5.35%	5.96%	8.78%	8.36%	5.10%	1.79%
	5.60%	4.51%	5.04%	6.46%	6.64%	4.07%	1.29%
	5.69%	6.71%	6.65%	6.23%	ND	5.01%	1.80%
	6.05%	ND	6.39%	6.34%	6.31%	4.52%	2.63%
	6.44%	5.43%	5.99%	5.18%	5.42%	ND	2.21%
	4.43%	4.83%	4.93%	5.95%	6.65%	5.03%	2.27%
	7.27%	ND	ND	6.78%	7.00%	4.54%	2.53%
	5.70%	4.73%	5.30%	ND	6.22%	5.15%	0.55%
	4.98%	5.19%	ND	ND	5.61%	3.85%	1.27%
	4.68%	3.30%	4.35%	6.07%	5.44%	3.54%	1.74%
	4.89%	5.30%	ND	6.45%	6.83%	ND	1.50%
	7.34%	5.57%	7.36%	5.48%	5.83%	4.21%	1.33%
	5.61%	8.23%	8.10%	5.47%	5.97%	7.17%	2.74%
	8.61%	6.16%	8.29%	9.46%	9.58%	6.89%	3.05%
	5.01%	7.20%	7.04%	5.89%	5.42%	4.69%	1.72%
	8.19%	5.41%	6.12%	8.87%	6.19%	5.55%	1.83%
mean %Cr:	6.03%	5.57%	6.27%	6.67%	6.50%	4.95%	1.89%
n =	15	14	13	14	15	14	16
std dev =	1.29%	1.22%	1.21%	1.36%	1.15%	1.04%	0.65%
			e-Size R				
	(Mass	Cr <sup>6+</sup> per	Mass D	ry Paint)	x 100%	)	
Stage:	1	2	3	4	5	6	7
		9.07%	5.82%	2.62%	1.08%	0.70%	0.50%
		7.99%	5.38%	2.14%	0.87%	0.64%	0.62%
		8.74%	6.15%	2.46%	1.05%	1.19%	1.17%
		8.56%	5.16%	3.54%	1.60%	1.14%	ND
		5.68%	ND	2.49%	0.81%	0.54%	0.51%
		7.35%	4.43%	2.41%	0.95%	0.25%	1.17%
		6.36%	6.01%	2.83%	1.20%	0.92%	0.81%
		6.96%	5.36%		1.12%	1.07%	1.00%
		5.37%	ND	1.93%	0.74%	0.92%	0.49%
		5.59%	4.24%	1.87%	1.00%	0.59%	0.48%
		5.48%	4.65%	3.32%	1.24%	0.52%	0.42%
		5.80%	4.64%	3.19%	1.23%	0.57%	ND
		5.46%	4.28%	4.00%	1.59%	0.66%	0.56%
		5.71%	4.61%	4.16%			0.67%
		4.97%	4.22%	3.40%	1.06%		0.39%
				1 0 000/	0.000/	0.500/	0.57%
		5.93%	4.65%	3.02%	0.99%	0.53%	0.51 /0
mean %Cr:		5.93% 6.56%			1.15%		0.67%
mean %Cr: n =			4.97%	2.89%	1.15%	0.72%	0.67%

# APPENDIX E-3: Raw Data Table for Solvent-Based Elastomeric, Polyurethane Primer Paint (TT-P-2760A, Type I, Class C)

Large Particle-Size Range Impactor (Mass Cr <sup>6+</sup> per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
	3.80%	2.77%	3.30%	2.98%	2.82%	ND	ND
	3.31%	1.91%	2.66%	3.15%	2.67%	1.91%	0.93%
	4.66%	4.31%	4.62%	ND	4.66%	2.99%	1.57%
	4.66%	3.92%	ND	4.25%	4.14%	3.25%	1.54%
	4.47%	3.94%	4.06%	3.86%	3.97%	2.60%	1.22%
	4.20%	1.80%	3.90%	4.18%	3.66%	2.63%	1.25%
	4.77%	4.59%	4.17%	4.83%	4.85%	3.03%	1.57%
	ND	4.52%	4.09%	4.54%	4.29%	3.16%	1.49%
	4.87%	4.44%	4.46%	4.13%	4.56%	1.13%	4.17%
	4.31%	3.83%	2.61%	2.87%	2.08%	1.89%	1.58%
average %Cr:	4.34%	3.60%	3.76%	3.86%	3.77%	2.51%	1.70%
n =	9	10	9	9	10	9	9
std dev =	0.51%	1.06%	0.74%	0.71%	0.94%	0.72%	0.95%

Small Particle-Size Range Impactor (Mass Cr <sup>6+</sup> per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
		3.30%	2.26%	1.57%	0.92%	0.43%	0.29%
		3.14%	2.12%	1.23%	0.83%	0.48%	0.32%
		3.70%	2.74%	1.59%	1.01%	0.56%	0.28%
		3.35%	2.73%	1.70%	0.93%	0.61%	0.42%
		3.89%	3.42%	1.80%	0.83%	0.43%	0.27%
		4.72%	2.63%	1.68%	0.60%	0.50%	0.35%
		2.33%	2.98%	1.66%	1.00%	0.45%	0.27%
		4.22%	3.02%	1.74%	0.94%	0.65%	0.70%
		4.24%	2.99%	1.70%	1.02%	0.51%	0.29%
		4.28%	2.98%	1.82%	0.92%	0.52%	0.36%
average %Cr:		3.72%	2.79%	1.65%	0.90%	0.51%	0.36%
n =		10	10	10	10	10	10
std dev =		0.70%	0.39%	0.17%	0.13%	0.08%	0.13%

Note: ND denotes data was collected, but lost before analysis was complete

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#### Vita

Captain Brian S. Rhodes graduated from Pace High School in Pace, Florida in June 1990. He entered undergraduate studies at the University of Florida where he graduated with a Bachelor of Science degree in Environmental Engineering Sciences in December 1994. He was commissioned as a Second Lieutenant through the Officer Training School at Maxwell AFB, Alabama in February 1998.

His first assignment was to the 37<sup>th</sup> Civil Engineer Squadron, Lackland AFB, Texas, where he served in a variety of capacities. After working as a program manager in the Environmental Flight, he served as the Engineering Advisor in the 37<sup>th</sup> Training Wing Competitive Sourcing Office. After returning to the Civil Engineer Squadron, he assumed the interim role of Chief of the Privatization Flight, where he was responsible for the oversight of the Department of Defense's first housing privatization initiative. In August 2000, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation he will remain at AFIT where he will serve as an instructor at the Civil Engineering and Services School.

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14. ABSTRACT  The United States Air Force relies on the corrosion inhibiting properties of chromate-containing primer paints to protect the aluminum skin of its aircraft. Hexavalent chromium (Cr <sup>6+</sup> )—the ingredient responsible for the corrosion inhibiting characteristics of these primers—is a known human carcinogen. The concentration of Cr <sup>6+</sup> in different particle sizes of paint overspray is important to understand health implications to painters as well as filtration efficiency.								
This research explores the possibility of a particle size bias in the Cr <sup>6+</sup> content of three commonly used aircraft primers: solvent-based epoxy-polyamide (MIL-P-2377G), water-based epoxy-polyamide (MIL-PRF-85582C), and solvent-based polyurethane (TT-P-2760A). Seven-stage cascade impactors collected overspray particles into distinct bins with particle size cutoff diameters ranging from 0.7 µm to 34.1 µm. The mass of the dry paint collected in each bin was determined and analyzed for Cr <sup>6+</sup> with an Atomic Absorption Spectrometer.								
with an aerodynamic diameter under	7 μm contained less Ci	6+ per mass of d	ry paint as the p	dry paint than larger particles. Particles particles became smaller. Particles less				
than 2.6 μm have a mean Cr <sup>6+</sup> conten	t of approximately one	third of the exp	ected value.					
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